FACHVERBAND FÜR STRAHLENSCHUTZ E.V.

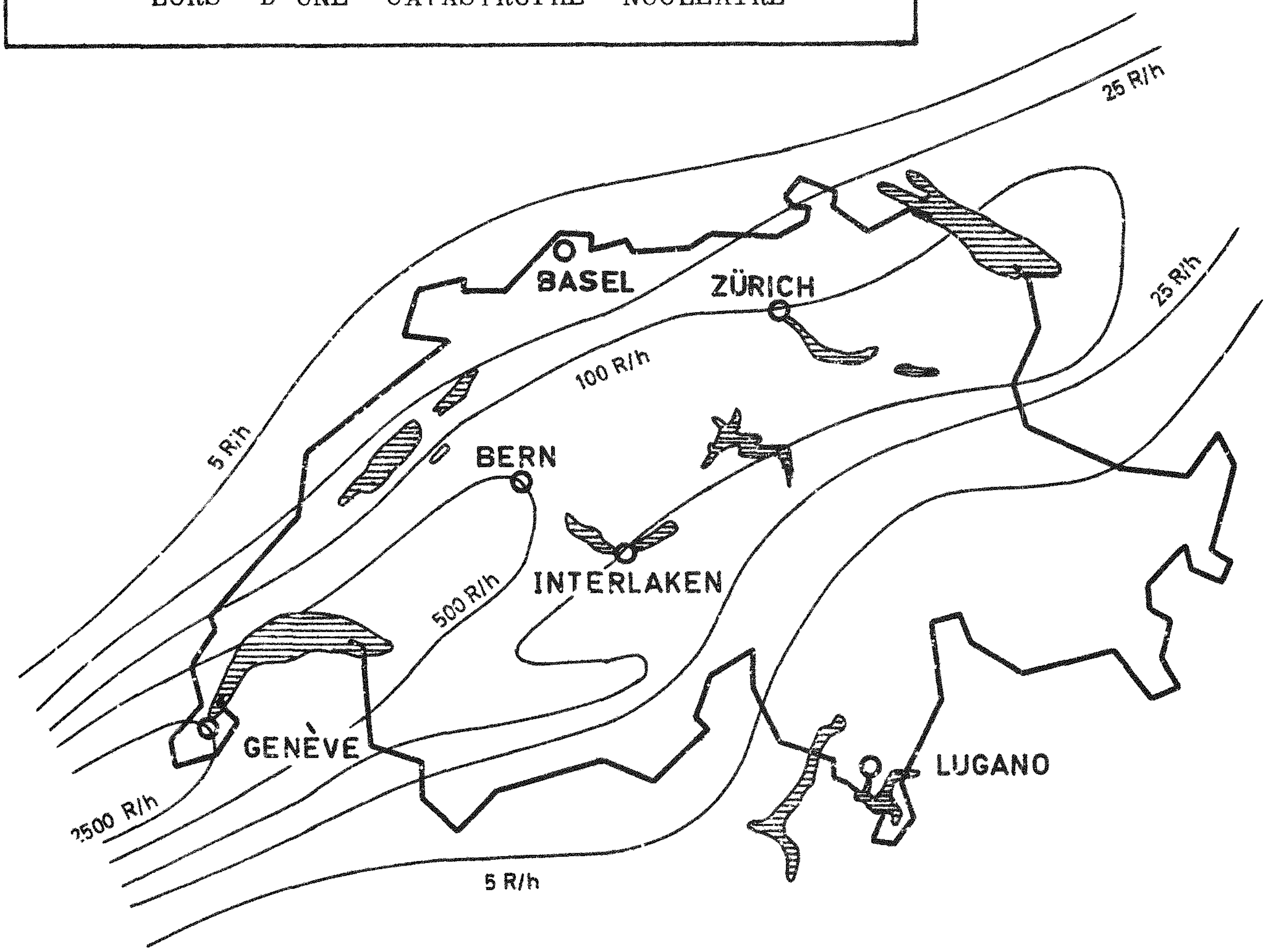
Mitgliedsgesellschaft der International Radiation Protection Association (IRPA)

PROCEEDINGS of a SYMPOSIUM

STRAHLENSCHUTZ DER BEVOELKERUNG
BEI EINER NUKLEARKATASTROPHE

RADIOLOGICAL PROTECTION OF THE PUBLIC
IN A NUCLEAR MASS DISASTER

PROTECTION RADIOLOGIQUE DE LA POPULATION
LORS D'UNE CATASTROPHE NUCLEAIRE



INTERLAKEN, SWITZERLAND, 26 MAY–1 JUNE 1968

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PLANNING FOR DECISION MAKING IN A NUCLEAR DISASTER

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It was roughly in the period around 1950, that I had my first close involvement with civil defense, and I suppose my personal reason for having been brought into it was my experience over the previous 20 years or so, with matters of radiation measurement and radiation protection. But, up until then my interest had been mainly with the clinical or the laboratory applications of radiation. I was somewhat used to modern warfare and its effects, but it was not without some degree of shock that I began to realize the enormously complicated interplays between all aspects of recovery and survival, following what then might be an atomic bomb attack. After my first week or so of fairly high level briefings on the problems, I felt myself just about overwhelmed, and yet at the same time I realized that it was through such groupings of experts, engaged in collective planning, that the problems were beginning to show some degree of manageability. This was not to say, that any of it was very nice, or very easy.

It was also about this time that I had my first neighborhood involvement with civil defense. Here, I was in the average neighborhood, where there was only one other person with the wide technical background needed to visualize and cope with the problem. The general civilian attitude towards a large scale nuclear disaster was one of utter hopelessness, and one of the early things that I tried to cultivate was some capability to provide a little reassurance about the problem. The first point that I would try to make then, was the fact that regardless of anything that we might do - or not do - in advance of a nuclear disaster there would be large areas of total annhilation, large areas of total survival, and large areas with all gradations of mixtures between the two. I would emphasize that however disastrous nuclear warfare might be at its worst, there would be large numbers of survivors and however altered and inconvenienced, civilization would survive. The idea of the elimination of man is nonsense.

Probably the biggest uncertainty in advance of the fact, is the knowledge as to who will and who will not survive. And again, no matter how much we do, or not do, in the way of advance planning for selfprotection, the final answer to this big question will be largely out of our hands. As an individual, or a collection of individuals, we might be wiped out instantly, or we might be fortunate enough - or unfortunate enough, depending upon your viewpoint - to find ourselves surviving in a strange and difficult world, but strongly driven by what is probably our most primitive and powerful instinct, namely that of survival and selfpreservation.

To me all of the effort, and planning that goes into our effort for survival is really directed toward easing the sorry plight of those of us who survive.

My answer to the prophets of doom, and those who whould give up before trying is this: First, you have no choice as to whether you will be the one to survive or die. On the chance of the latter, any little tiny thing that you do in advance in the way of planning, thinking, or preparing against the eventuality, will put you to some degree that much ahead of where you would otherwise be if, like the proverbial ostrich, you hide your head in the sand and hope that the problem will go away.

Since this Conference is primarily devoted to the radiation aspects of the problem, and since one of its primary aims is to emphasize the involvement of health physicists and other radiation experts in the problem, the comments which I am making, while basically of a general nature, should be thought of in the context of radiation, rather than in any of the other facets.

A point that I especially would like to emphasize, has to do with what I consider to be the absolute necessity of close collaboration and coordination between pre-disaster and post-disaster planning. It is true that many parts and requirements of the planning for these two are quite different as to their basic nature and the kind of people who will be required to cope withe them. In our country, we have watched this go through a complete cycle. Starting off with joint management of pre-attack and post-attack planning, then complete separation between the two, and now recognition of the actual inseparability of them, and a gradual reblending of their combined efforts. It now appears to be broadly recognized, that the goal towards which all planning must be directed is that of long-range recovery and that any intermediate goal as a plan to itself, is of very limited if any, value.

There are three stages in the planning process, although each of these can be broken down into many fine steps:

The first stage of planning is that for sheer survival. This includes the preattack planning and organization, shelter identification and construction, supplies for the shelter period up to emergence and so on. Precisely where this period ends is not easily defined, and perhaps should not be defined in any sharp way, but rather blended over into the next phase. Perhaps we might say that the immediate survival period might extend up to some three months after the attack. It is during this period that there will be the greatest attrition of those over-exposed to radiation - or injured from any variety of causes.

The second period of concern is that extending up to perhaps three years after an attack. It has been said by many that, if by this time the physical health of the surviving people, and the economic health of the country does not at least show some signs of leveling off - - if not of some degree of improvement, we might most likely look forward to a rapid further decline. It is during this period, that there will have to be many decisions in which the radiological aspects of the problem will be the major ones. Quick and accurate decontamination procedures will, for example, have to be carried out within the first few months to make available certain critical places or facilities. These can probably be rather limited in magnitude and are amenable to "crash" efforts. Places will have to be rendered sufficiently clean, so as to allow at least partial occupancy.

Over the longer range, however, there will be vast areas of lower level contamination, but levels nevertheless, such that they cannot be allowed to persist indefinitely because of their influence on our food chain, or on our general dwelling capability.

It is particularly in this area of rehabilitation of farm lands, forests, home land, etc., that the radiological recovery plans will be enormous and where much of the success will depend not necessarily on the development of new principles, but rather the development of fine degrees of judgment as to when to take - or not to take - a particular action.

In the attack phase of a nuclear disaster, and in the recovery phases - particularly the earlier stages - there will be unbelievable requirements for ruthless decision-making, or at least so it will seem to others. But under these

circumstances there is no opportunity to practice, or even show the niceties to which most of us are accustomed. The ruthlessness can be ameliorated to some degree, only by removing from the decision as much arbitrariness as possible, and this can only be done upon the basis of knowledge and advance planning.

Within the radiological area there will have to be decisions involving which lives are to be saved and which space is to be used by people, or by animals. Triage is an old word, but one which has come back to our consciousness in thinking of nuclear disasters. A decision as to whether or not to help some heavily wounded people as against those more lightly wounded will not be so difficult because, for example, one will be able to quickly see that a person will bleed himself to death in a short time. The decision is much harder where a person may show no visible injury, but at the same time be so heavily exposed to radiation that he also will not be able to survive, and on the basis of radiological information he will be selected "in" or selected "out". That is a decision I hope none of us here will ever have to make, but the more we train for the job, the more wise will be our decision of we ever do have to make it. And so also will our conscience rest more easy.

As I have been emphasizing, the "decision process" will comprise many kinds of situations. The more obvious, broad problem areas lie in the application of medical care, and the providing of food and shelter for those who have survived. And then there will be the ultimate problem of shelter emergence and decontamination. You can almost take these in order. For the injured - medical care is first, or they are not preserved for the later steps. For the injured who are under care as well as for the uninjured, the other stages all fall together.

After the emergence and early survival period - lasting perhaps a matter of a few months - the next step is, of course, to try to reestablish some industrial capability by again starting up undamaged operations, by repairing or canibalizing the damaged facilities, or by completely rebuilding some of the capabilities that are critical to our continued build up. Again, all of these are complexly inter-related, but from the point of view of this Conference all have one common aspect; there will have to be a constant input of radiological information on which to base decisions.

Coupled with this of course, will be problems of economic nature and I have heard it commented that we will not have time to be thinking about economics under such circumstances. In terms of economic theory, this may well be the case, but if we have not done a lot of thinking about the economics of this situation beforehand, we will find ourselves in deep trouble when the situation is upon us.

A new kind of economics will have to be applied, especially in those cases where it must be necessary to produce some critical item, but where the normal facilities are no longer available. We will, without question, move to processes which in normal times would be regarded as economically unfeasable - or we will move to new kinds of materials, which for the same reason have not been extensively used in the past. There will undoubtedly be many instances when the "go" or "no go" decision will depend upon radiological considerations. And again, those things which will work best are those that were thought about beforehand.

In the very long-range - now the matter of a few years to a few decades - we will have the problem of latent injury due to radiation, the undoubted increase of various forms of neoplasia, the shortening of life span in ways not easily

relatable to radiation. These will be accompanied by complex social problems and the possible need for the development of different approaches to the medical care of people.

Still another problem area, will be of an ecological nature, where the delicate balance of animal and wild life may be disturbed, where woodland and farmland will be denuded of its surface product upon which man has become dependent. The extent to which we can understand these problems, plan for them in advance and make the necessary decisions in the right way, and at the right time, may well be the deciding factor as to whether we will be able to move reasonably quickly back into a viable civilization, or whether we coast more deeply into chaos, before the rebuilding process can really start.

Radiological decisions will by no means be the only ones which will be required and for which an enormous amount of training, and ingenuity will be required and for which large numbers of people, and educational material will be required. But radiological considerations will surely influence all the others.

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OBSERVED FALLOUT PATTERNS AND COUNTERMEASURES TAKEN

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The stated topic of this symposium is, "We want to discuss the radiation protection measures after a nuclear mass disaster by which large areas have become so severely contaminated with radioactive material that it constitutes a major hazard for the public." Fortunately it is not possible to document directly this topic because such an event has never occurred. We are forced then to look for other situations that may provide relevant information and guidance to our discussions.

There were three incidents that occurred following atmospheric nuclear weapons test detonations, and although they have been reported previously, bear recounting for they do show (1) what decisions were made and on what bases (2) the manner in which the decisions were carried out and (3) the results of the protective actions taken.

But first let us take a look at the various nuclear weapons test sites (slide 1). I realize you cannot read the captions but the slide does indicate the locations where over 350 nuclear explosion tests in the atmosphere have taken place. (see: Paper 5.3., Fig. 1)

The first incident to be recounted was when there was a relatively heavy fallout on the Marshall Island in the Pacific following an atomic test detonation on March 1, 1954 that required the evacuation of 239 inhabitants. After the event I attempted to reconstruct the fallout pattern (slide 2) to show the estimated radiation doses that personnel would have received over the 48 hours following initial appearance of the fallout if they had been present without any shielding. The highest exposure to the inhabitants before their evacuation was about 175 roentgens.(see: 5.3., Fig. 2)

A more detailed description of the event and what decisions were made and on what bases will be given Wednesday morning in Session 5. It should be pointed out here, however, that the event illustrates the necessity of, and benefits to be drived from good safety plans that are fully implemented. The inhabitants were spared very high exposures yet there was not a single non-radiation injury during the evacuation. But it should be pointed out quickly that these factors were abetted by two conditions (1) there were abundant capabilities at hand - aircraft, ships, equipment, trained personnel, etc. - and (2) the inhabitants were unaware of the potential hazard and were very cooperative. If there were a large and less amiable population, imbued with fear, rightly or wrongly, and there were only limited capabilities at hand for protective action - as might prevail under the conditions suggested for this symposium of a nuclear mass disaster - then there could be a different result.

The second incident occurred at St. George, Utah, U.S.A. in 1953. The next slide indicates the potential radiation doses to personnel who continued to live in these areas for a lifetime - but, of course, most of the total exposure occurred in the first week. The total doses estimated afterwards were not large yet the circumstances under which the fallout occurred led to a decision to send 4500 persons indoors for a period of two hours.(see: 5.3.,Fig.5)

Those 4500 persons were spread throughout St. George, Utah - hundreds of children were at school and play - cars and trucks were moving about the city on their normal business - this would be the first time that action would be taken with such a large community and on short notice. Instructions to evacuate immediately might induce a panic with its attendant hazards and would, in fact, bring persons out of their homes, schools and offices into the open during the time when the fallout was occurring most abundantly. Again, more details will be discussed in Session 5 in brief nearly all of the 4500 persons were under cover within 15 minutes without panic and without any injuries. The key to this success was the prior programm of education that had been conducted with local officials and the general public.

I have included on the next slide another fallout pattern near the Nevada Test Site since it represents about the extreme in narrowness of any pattern observed, and includes the highest value of potential exposure to personnel from any single fallout from nuclear tests at the Nevada Test Site. Also, the small area shown, where the fallout was higher than in the surroundings, was a small river valley running diagonally across the fallout field.

The third incident was in 1962 at Salt Lake City, Utah, U.S.A. Here countermeasures were instituted by local and state health authorities to reduce the iodine 131 content in milk. Cows were placed either on dry feed or their milk was diverted into milk products. In addition, citizens were alarmed to the point where they switched to powdered milk or eliminated milk from the diet of children. The incident affected about 180,000 local inhabitants of Salt Lake City. The unfortunate thing about the incident was that fear arose and action was taken primarily because of lack of understanding of the radiation protection guides currently in effect. The guides themselves were in need of clarity as to their meaning and applicability. The incident shows the necessity for scientists to develop radiation protection guides that are as free from ambiguity as is humanly possible.

Finally, I had been asked to speak about the incident in Spain where plutonium was released from two nuclear bombs and contaminated the immediate areas. Since this request was made, however, Dr. Ramos and Dr. Iranzo who are much better qualified to do so than I, have kindly agreed to discuss these data. Therefore, I will limit my remarks to the following.

Although there have been several incidents while transporting nuclear weapons, some of them severe enough to cause the chemical high explosive to detonate, there never has been any nuclear contribution to the yield. Of course, if the chemical high explosive does detonate, the radioactive contents of plutonium and uranium will be physically scattered into nearby areas.

In such an event, field and laboratory tests indicate that the principal hazard would be inhalation of the plutonium during passage of the cloud - amounting to some 5 to 10 rem to the lungs in areas of highest air concentrations. The standard for radiation dose to the lungs of atomic energy workers is 12-15 rem <u>each year.</u>

Although field and laboratory tests indicate the potential exposure from resuspension of the plutonium after initial deposition would be even less than the 5 to 10 rem, nevertheless in the case of Palomares it was possible and feasible to remove much of the plutonium from the environment by simply scraping off the solid soil to a depth of two to three inches. Other measures such as deep plowing were taken to reduce any resuspension. (Plutonium oxide is quite insoluble so that very little finds its way from the soil into the roots of plants.)

The next slide shows the areas of contamination and the actions taken. The soil that was scraped - about 283 cubic meters - was transported to the U.S. Atomic Energy Commissions's Savannah River Plant in the State of South Carolina. (see: 5.3., Fig. 6)

One final story. Following a cratering experiment using an underground nuclear explosive, at the Nevada Test Site in the spring of 1964, some radioactivity vented and contaminated pasture lands to the north of the site. As planned, radiological monitors went into immediate action. Among the many surveillance activities conducted was the daily collection of milk from the affected farms. In the midst of these daily collections, I received word by telephone that one of the cows had died. This was most difficult to understand since the measured levels of activity, both external gamma and iodine 131 in milk, where very low. An investigation revealed that samples of milk were sent from the farms to the laboratory on a daily basis. On this particular day no sample of milk was received from one farm but instead the monitor had written a note stating that the cow had "kicked the bucket", which also is a slang phrase meaning someone has died. Further investigation verified that indeed she had literally kicked over the bucket and that was why there was no milk sample from that cow for that one day.

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Developments since the 1963 WHO Seminar in Geneva

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I have been asked to mention changes in our attitude to emergency problems caused by radiation which have occurred since the Seminar on the Protection of the Public in the Event of Radiation Accidents which many of us attended in Geneva towards the end of 1963 (see World Health Organization, 1965). It is always difficult to give a correct impression of developments which have occurred since a given date because new concepts evolve steadily even though their full implications may not, at first, be fully recognized. Thus, for example, Report No. 29 of the National Committee for Radiological Protection of the United States (1962) to which reference will, I am sure, be made during this meeting, had been issued several months before the Geneva meeting but on a number of aspects it could reasonably be regarded as foreshadowing developments which were little considered at that meeting. It seems, therefore, that the fairest way of discharging my task is to contrast the points of view which are evident from our present programme with those which guided our discussion in 1963.

During the next four days there will undoubtedly be reference to the results of many investigations which have been published during the last five years. More elaborate models of physical situations which might be faced in emergencies have been developed and more detailed evaluation of the biological effects of ionizing radiation has been made. In the main, however, the new information has necessitated few major changes in the more important basic concepts on which our assessments rest. For example on the biological side the largest errors in earlier concepts appear to have been with regard to the sensitivity to radiation of some major agricultural crops; this, however, is a minor part of the overall problem.

Obviously this improvement in our basic data is gratifying, but none the less it is important to bear in mind limitations to the practical usefulness of our conclusions which cannot be eliminated by research. Among these the most obvious is our inability to predict, except within very broad limits, or to visualise coherently, the actual circumstances -

physical and sociological - which may arise in any future emergency. The refinement of biological and physical models cannot eliminate these problems and their elaboration beyond a certain point may thus help little in solving the practical problems of planning how populations could be protected. Indeed the creation of complex theoretical models may be a positive disservice as their mathematical elegance can sometimes conceal our ignorance and uncertainties. Despite its usefulness the computer cannot generate information which we lack.

Perhaps the most significant developments since we met in Geneva are due to the re-evaluation of basic aspects of radiobiological protection to provide a broader and more balanced philosophy by which action can be guided. That meeting was undoubtedly a powerful stimulus to this development; when it was planned the belief was widely held that in emergencies, as in occupational situations, action to protect the public could be decided largely on the basis of predetermined maximum permissible levels. Indeed three of the nine sessions in Geneva shared the general title of "The problem of setting maximum acceptable levels of radiation exposure to the population in emergency situations". Discussions which ranged from problems of estimating biological risks to more practical questions showed the inadequacy of this approach. A meeting of some 200 scientists and administrators could not be expected to agree entirely on all questions, but the report of one of the Seminar's Working Groups stated "There was a unanimous feeling that the term maximum permissible dose or acceptable dose should never be used in the context of radiation accidents. With regard to action levels there was general agreement that no one level applicable to all situations should be laid down".

Two years later, Publication 9 of the International Commission on Radiological Protection (1966b) brought further and considerable clarification. A clear distinction was drawn between the principles of radiation protection against controllable sources of exposure as opposed to those which could not be directly controlled. It was explained that the maximum permissible levels recommended by the Commission applied to controlled sources only, that is to say to occupational situations. In emergencies the Commission recognized that the relevant question to consider was: "What remedial actions may be available to limit the amount of exposure and increase chances of recovery? In such cases the hazard or social cost involved in any

remedial measure must be justified by the reduction of the risk which will result. Because of the great variability of the circumstances in which remedial action might be considered, it is not possible for the Commission to recommend action levels which would be appropriate for all occasions." In its Publication 8, ICRP (1966a) offered what assistance it could to those responsible for making decisions by assembling information on the magnitude of risks from radiation. This approach - we may describe it as a wedding between academic and administrative wisdom - now seems so obvious that it deserves little comment. Some of us, however, may recollect discussions such as that which Mayneord had in mind when he wrote in his splendid monograph on Radiation and Health (1964) "I have myself sat spellbound as well-meaning administrators proposed to set in motion measures which would have caused untold social confusion and alarm, because a single measurement of concentration of a radioactive material approached a level set for years of continuous consumption." That comment epitomizes a view which was widely held, often unconsciously, when the effects of radiation were less familiar - namely, they could in all situations be regarded as creating a category of risk entirely different from all other types of risk to which the population might be simultaneously exposed.

There could be no clearer evidence of a more realistic approach to disasters caused by radiation than the difference between the types of emergencies which will be considered in the next few days and those which occupied us at the Geneva meeting. Discussion there was concerned largely with reactor accidents and some speakers assumed, though they offered no data, that in such circumstances the population of a whole nation might be at risk and that the area affected might even spread beyond the borders of a single country; among remedial action suggested for such circumstances, was the removal of strontium-90 from agricultural land, although again no evidence was presented, and indeed none existed, that the presence of that nuclide in the soil could ever become a source of appreciable hazard to the population. The reports of a meeting on reactor siting organized last year by the International Atomic Energy Agency (1967) now show that at worst it is necessary to envisage only relatively local and transient environmental problems after industrial accidents. Furthermore clear reasons are emerging that, viewed overall, it is rational to regard the development of nuclear power programmes not

so much as creating a new risk to the population but rather as providing an opportunity for eliminating some of the greater but more familiar risks of the coal era.

In contrast when we turn in this meeting to the devastation which nuclear warfare could create we have no corresponding grounds for comfort other than the hope that nuclear war will never occur. However, if we are to make progress towards our objective, which has been described as planning to assist the survivors to survive, it is even more important than in the lesser peacetime problem to make an objective assessment of all aspects of the risks to which populations might be exposed both from radiation and other sources. The exaggeration of one aspect of the overall hazard, relative to others, could encourage the unprofitable dissipation of limited resources. Thus one of our most important tasks is to identify those routes of exposure which will dominate in different circumstances and limit our discussion to them, ignoring trivial aspects. We should be assisted in achieving this perspective by the discussion on the weighing of risks from different sources which took place at the Geneva Symposium and also by the subsequent publications to which I have referred.

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PALOMARES TWO YEARS AFTER

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A little over two years have gone by since the accident which has been the subject of two or three books and of news bulletins which traveled around the world several times, and were presented under the most diverse journalistic slants. For that reason, we decided to present an accurate, objective report in Monaco in 1966, on what we saw, did, and thought, for we considered it our inescapable duty to inform all those who take an interest in and live with these problems of protection against ionizing radiation. Since all stories have a second part, we who presented the first report now want to offer its continuation, on behalf of the entire team of coworkers of the Medicine and Protection Division of the Atomic Energy Board, which has worked enthusiastically and efficiently on the different aspects of the problem from the very beginning.

As we said in our first report, the accident took place at a height of about 10.000 meters. The pieces of the planes fell over a very wide area. Many pieces of both planes fell outside the area carefully delimited to determine the zero line. Test made at the points where these pieces or fragments of the planes were found showed no signs of radioactive contamination; such contamination of pieces was found only in the ones that fell within the circumscribed areas. This told us that the dispersion of the radioactive spray did not occur in the upper strata of the athosphere. If this had been the case, the contaminated area would probably also have been much wider, and the contamination would have been characterized quantitatively by two features which were not present in this accident: one, greater uniformity and two, lower values per surface unit. The variations in distribution, following the lines of the direction of the prevailing wind, with decreasing concentrations from the center outwards, and the most densely active areas (2 and 3) at the points of impacts, prove that the explosions of the conventional payload took place when the bombs hit the ground.

The dispersion of the houses and of the scattering of the parts may have changed the probability of the occurrence of a mecanical impact from what it would have been if the houses had been more tightly grouped in any of the affected areas. The lack of this type of accident was very fortunate, for there were no regrettable bodily injuries to the townspeople.

One of the lessons derived from our experience that should not be forgotten is that the pieces or fragments of contamined material, no matter how small, must be meticulously sought, for first of all, they will be found completely unsuspected distances away, and in the second place, many of these fragments, covered with dust which adheres to the usually greasy or damp surface, are very highly active. The potential danger of these fragments is very great, if they are picked up by someone (especially children) who blows on them to remove the dust. Because of the high concentration of the radioactive element (Pu or U) in the dust, that person may very well breathe in a quantity large enough to be significant. It is therefore wise to advise all persons who might find possible contamined fragments or pieces to take care not to handle them.

Another lesson of special interest is that cultivated and wild plant life must be cleaned as well as possible, not only because of their contamination but because they may be hiding such fragments which would otherwise not be visible.

With regard to work on soils, we think that deep-furrow plowing or with the plows used to break still uncultivated ground, will produce sufficient renewal in the layers of soil to dilute considerably the radioactive element. If several cuts are made on successive passes, dilutions so large will be obtained that the land can quickly be farmed again (as happened in our zone 5). We think that the mixing of layers of soil containing different amounts of moisture will result in the formation of denser conglomerates, for the radioactive metal core with high surface activity will adsorb inert particles of silicates or other compunds which surround it and stop it from being directly accessible.

We have reviewed Reitemeier's study presented at the Geneva seminar in 1963, and believe that the greater dispersion of the radioactive elements in those areas which do not require the elimination of densely contaminated surface layers can be achieved by several passes with rotavators under a fine water spray. The entire arable part of zones 3 and 5 was treated in this way, and we verified its high effectiveness. Furthermore, the job takes little time when, of course, the motorized equipment which is nowadays in service practically the world over is used.

A difficult problem was the decontamination of the sides of the houses; however, we solved it by applying several layers of paint. We achieved two ends with this procedure: first, the fixation of the contamination so as to prevent resuspension in the air which would allow it to enter the dwellings through windows or openings in the walls; and second, the interposition of layers of dense material (in this case, calcium oxides) which absorb the weakly penetrating alpha radiation. Successively applied layers of this type of paint will create ever increasing security that traces of radioactive elements will not get into the ambient air. Of course, this procedure will not be so effective with other elements with more penetrating radiations.

We think that the best form of treatment for contamined plants is incineration. However, there must be careful determination and selection of the area in which incineration is to be done, of the density of the amounts of plants to be incinerated (so that all of them will be completely reduced to ashes with no areas left unexposed to fire), and finally of the wind direction and velocity (to prevent the smoke from reaching inhabited areas.). We incinerated the dry bed of the River Almanzora near the beach, taking advantage of the night breezes which blow from land to water.

The case of the town of Villaricos which is separated from Palomares by the river and by a hill, is also interesting. The zero line ends near the river, but nevertheless, we found a contaminated area in the town of Villaricos and its surroundings, with much lower values than in Palomares, but still an area which we did not expect to find. The hill was not enough of an obstacle to prevent a low-concentration radioactive cloud from sailing over it, driven by the strong prevailing wind, and being deposited several kilometers beyond the zero line. Thus, we do not think the suggestion we made in Monaco that an area up to five kilometers away from the zero line be explored is at all exaggerated, but rather very conservative, for in each particular case there will be a possibility of meeting up with surprises of this sort.

Dr. Iranzo will set forth the results and precise data on our work, which has continued uninterrupteldly since we first set foot on those sunny lands.

Now, life there has returned to normal, the disruptions having lasted only as long as was absolutely necessary. If the harvests of their characteristic crops are irregular, this is a result of accidental inconsistencies in the climate,

which this year , for example, was marked by extremely low temperatures at the crucial times of maturation and harvesting of the crops (tomatoes, mainly) and the poor quality of the irrigation water, which is mostly inappropriate, according to the reports of the INIA. That whole area is an outcropping of sea bottom, uplifted by the tilting of the continental shelf many thousands of years ago. The low annual rainfall makes the salinity of the soil and of the running waters, that are trapped in deep wells even higher.

Two years after the accident, we still have four atmospheric dust-collecting stations which, because of the results we have thus far obtained with filter papers placed at a height of one and a half meters above the soil, we are going to change to a height of one half meter, to see whether there is resuspension closer to the ground. We have placed two permanent meteorological recording stations at the two points of greatest interest. We take soil, water, and crop samples as well as samples of wild plant life and non-domestic animals, preferably the ones that can give us the most realistic indication of contamination because of long contact with the soil and plants, such as snails. A modest building is used as the place where we prepare and classify the samples. We have begun some experiments with the INIA to determine whether any of the fertilizers most widely used by the farmers in the area facilitate uptake of Pu by the plants. The presence of Pu in the lungs of a group of people, some of whom were exposed at the beginning and others who were chosen as controls, has been tested with a whole body counter. We also checked for the presence of Pu in three samples of the urine of these people, taken over 24 hours under the most carefully controlled conditions. The results were negative for both the urine analyses and the tests with the whole body counter. We have on file hundreds of readings for soils and plants, houses and a large number of locations, dozens of graphs, and many other facts which we hope to be able to collect some day in a single volume which will give these who have to face similar problems food for thought and study.

The last three lessons that I want to point out here as I conclude this brief report are: one, the importance of dealing with the psychological factor in the common people. Apart from the implications of an economic nature which may or may not be present in each case, it is very important to be solicitous with these people and not to be sparing in employing all possible means to enlighten them and convince them of the groundless nature of some of their fears. In this regard, I want to make mention of the decision I had to make the very day I arrived in the area, regarding the appropriateness of evacuating it completely as a newspaperman had proposed to a mayor of a nearby town. If I had authorized this, I am sure that even this long after, many people would not yet have returned to their homes, and the material and moral damage done to the region would have been incalculable. Hence, such a decision should be pondered very carefully.

The second lesson is that, while the Civil Protection Agencies can supply the personnel and the material equipment for field work, it is the National Atomic Energy Institutions, be they called Headquarters, Commission, or Boards, that should keep strict scientific control of the thousands of details of a technical nature that come up constantly.

The third and last is that well-trained prospecting teams, accustomed to hard work in the country, should always be kept available. I want to emphasize once again how much help we got from our teams, which we would never have had if these teams had had to be organized on the spot.

We hope that our modest contribution, together with that of our Danish collegagues, will provide useful study material and facilitate action in the case of another like or similar accident, which we pray to God will never occur.

A preliminary report on the B-52 accident in Greenland on January 21, 1968.

0.5

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It is a great pleasure for me to have the opportunity to contribute to the discussions of this symposium by giving a brief survey of the administrative and radiological aspects related to the B-52 crash, which happened recently in the northern part of Greenland.

On Sunday 21 January this year an airplane belonging to the United States Strategic Air Force, a bomber of the type B-52 carrying nuclear weapons, passed through the Baffin Bay on a routine flight following a northbound route. When cruising over international waters, about 2oo km south-west of Thule, the plane caught fire, and it was necessary to ask the Thule Air Base for permission to undertake an emergency landing. Having received this permission the course was changed towards the landing strip, but shortly before arriving there the captain was forced to order the crew to bail out. The unmanned plane made a left turn and crashed on the ice of the Bylot Sound - between Saunders Island and the mainland - 11 km west of Thule. This accident happened at approx. 4.3o p.m. local time.

As an introduction I shall give a short description of the administrative measures, which were taken by the US and the Danish Authorities in order to cope with the consequences of the accident. Hereafter I shall report on the main points of the radiological problems and on the subsequent clean-up operation, which was undertaken to prevent the endangering of anybody by radioactivity, both in the near as well as in a more distant future.

The accident became known in Copenhagen on monday 22 January, and Tuesday morning there was a meeting in the Danish Ministry of Foreign Affairs. It was decided - in agreement with the US State Department - to send a group of radiation experts from the Danish Atomic Energy Commision and the Danish National Health Service to the cràsh scene in order to cooperate with the scientific and military personnel, which was immediately sent to Thule from the United States. The members of the US scientific mission were Dr. D.M. Bruner, Dr. W.H. Langham and Dr. J. Wolfe, and the chief of the Disaster Control Team was General R.O. Hunziker. The Danish team consisted of Dr. H.L. Gjørup, Dr. P. Grande, Dr. O. Kofoed-Hansen and myself.

Due to a heavy storm we did not arrive in Thule before Thursday evening. Upon our arrival the Danish liason officer brought us in contact with the American mission, and we were immediately informed about what was known at the time. Although four days had passed since the accident occurred, only a general survey of the situation could be given. It must, however, be borne in mind that the weather conditions are very bad in the arctic at this time of the year: Temperatures down below - 4o^{o} centigrade, heavy storms every 3rd or 4th day, and total darkness around the clock, with the possible exception of a few hours of twilight.

Since then Operation Crested Ice was carried out in close cooperation between the growing number of US and Danish scientists and the staff of General Hunziker. The clean-up operation itself was carried out by US military personnel which at a time comprised more than 7oo people. At a later stage this activity was supplemented by Danish civil technicians and workers, ordinarily associated with the Danish company running the civil affairs of the Air Base.

The original team from Denmark returned to Copenhagen after two weeks, when the situation was quite well in hand. Since then other Danish health physicists have been in Thule in order to follow and to participate in the operations - at first on a permanent basis, later on in longer or shorter periods.

In the middle of February a US delegation (under the direction of Dr. C. Walske, Assistant to the Secretary of Defence on Atomic Energy) went to Copenhagen to discuss the further steps to be taken as a consequence of the radiological survey, which had been carried out by that time. Later, in the second part of March a Danish delegation (headed by Dr. H.H. Koch, Chairman of Executive Committee of the Danish AEC) went to Washington to decide on the final dispositions related to the clean-up operation. Today this operation is finished, and what remains to be done is merely to check that nothing unexpected may appear.

Immediately after the crash the Danish liason officer took the initiative to warn the small number of eskimos regularly hunting in the area about the possible danger of radioactive contamination. On the 29th of January all traffic in the area around the Bylot Sound was officially prohibited in order to take care of any eventuality. These restrictions could already be abolished by the end of March. Today the crash scene is marked by stanchions connected with a rope in order to avoid unnecessary traffic. However, ice melting already prevents staying in the area.

It may be added that from the day of our arrival in Thule the international press was allowed to follow the operations. I think this attitude is one of the reasons for having minimized overestimates of the hazards and misunderstandings have as far as possible been avoided.

I shall now turn to the radiological aspects of the accident. However, time permits only to give a summary of the main points. Furthermore, I shall characterize activity levels by general terms only. To give figures would make it necessary to describe in detail how and where samples were taken.

1. The airplane hit the surface of the ice with high speed at a glancing angle. At the moment of impact the conventional explosives of the four hydrogen bombs were detonated, with the result that all parts of the plane were blown apart. Around the point of impact the ice was broken to a distance of approx. 25 m, but this area was of course immediately refrozen.

Due to the forward direction of the velocity, debris and fuel were spread over a drop-shaped area with the approximate size 7oo x 15o m^2. A tremendous fire developed which lasted for more than 15 minutes. Consequently the spread of plutonium into the atmosphere, to the water, and to the ice and snow had to be taken into consideration.

2. The radiological survey, which was immediately carried out, revealed that the main amounts of plutonium were confined to a limited area, and that radioactive contamination was fixed to the debris. Due to a heavy eastern storm a few days after the crash the original 1o cm snow crust was covered with a thin layer of fine snow, so that it was possible to walk around without being contaminated.

3. About a week after the crash "Operation Pick-up" was started. Walking shoulder to shoulder the monitoring teams picked up all smaller pieces of debris, and these pieces were put into containers, which were subsequently sealed for transportation to the US. Large pieces were first collected in big stacks, they were overpoured with water and secured against removal by storms. Also these parts were later contained for transportation.

4. After all accessible debris was removed a radiological survey of the contaminated snow and ice was undertaken. Measurements were carried out radially from a fiducial spot and in this way contour lines of the spread radioactive material were obtained. The measurements showed that from a health physics point of view the only significant plutonium contamination was confined to the snow of the area where the fire had taken place.

5. As a next step the contaminated snow - approx. 12.ooo m^3 - was removed and stored in a large number of empty steel fuel containers which were available at the site. Obviously this was a very difficult operation, but it was carried out without spreading any significant amounts of plutonium to the outside. The radioactive snow (water) will also be brought to the US. By far the major part of the contaminated snow was removed in this operation.

6. A large number of core samples of the ice below the burned area were taken and showed that this ice was undamaged and essentially clean (approx. 2oo core samples, ice thickness approx. 8o cm). In the area of the crushed ice at the point of impact some radioactivity was found, but in such amounts that the removal of the ice was not regarded to be necessary. This area has later been covered with carbonized sand to speed up melting - due to the increased absorbtion of solar energy - before the ice breaks up in the bay probably sometime in July.

7. Due to the heavy fire following the crash, particles of various sizes covered with Plutonium were injected into the atmosphere. Since an unknown amount of these particles might have settled in the area surrounding the crash site, snow samples were taken in Thule, and especially "downwind" in the Bylot Sound and on the surrounding coast lines. Measurements of these samples showed such activity levels that nobody could be endangered, and consequently no special measures were taken.

8. Evidently radioactive particles might also have been lifted into higher layers of the atmosphere, from where they could be spread over very large distances, preferably towards the west, due to the prevailling wind direction. To check this point samples were taken from airplanes bound for Thule or passing across Greenland on ordinary traffic routes. None of these samples showed activity above background, and the same was found for snow samples taken at places far away from Thule (Søndrestrømfjord, Godhavn etc.).

9. Special attention was given to the question of spread activity in the water and the bottom of the 2oo m deep Bylot Sound. Water and bottom samples taken at various places, showed activity levels far below the limits which could be a hazard to human beings by passing through the food chain.

1o. To secure that animals (such as walrus, seals and mussels), who are used as food by the eskimos, were not contaminated, a number of biological samples were taken and measured. Even sled dogs and foxes were shot and measured for the sake of safety. But in all cases it was ascertained that the radioactivity levels were far below what is considered tolerable.

Consequently it is absolutely impossible that radioactivity can be carried along the Greenland coast line to the places towards the south, where fishing is carried out on a commercial basis.

11. Evidently protection of the public was the final aim of the radiological survey and of the clean-up operation. It can be said today that none of the eskimos staying in the area at the time of the accident have become contaminated, and that the same goes for those assisting in the initial search on the ice. Also the US and the Danish personnel taking part in the time-consuming clean-up operation were not contaminated beyond standardized levels, although no masks were used against inhalation of snow and dust. This was ascertained by testing all protective clothing with alpha-monitors and by taking nose-swabs. All technical equipment used in the operations was decontaminated according to good health physics practice.

12. To check that nothing unexpected may happen in the summer, when the ice breaks up and partly leaves the Bylot Sound, the Danish AEC will conduct an ecological program and a search of the shore lines for floating debris.

Let me finish this report with the following remarks: The B-52 crash in Thule has caused no casualties among the population neither in Thule nor in the surroundings, and the area will be safe for the future.

This is partly due to the fact that the crash occurred at a convenient place, far enough away from Thule to prevent direct casualties, and close enough to make the recovery effort succesful. I would, however, like also at this place to give due credit to the US scientific and military staff and personnel working at Thule. Operation Crested Ice was, from the US side, carried out with the greatest competence and with a terrific effectiveness with the result that the operation could be called off about two months after the accident. The cooperation between US and Danish people at all levels has been perfect, since everybody was working toward a common goal.

However, credit should also be given the scientists and other personnel in the United States and in Denmark, who have carried out the tedious work of studying the collected samples.

What I have reported today does not contain anything which has not been said in public before. But it gives, I think for the first time, a competent and general survey of the Thule accident.

E

THE NATURE AND BEHAVIOR OF LOCAL FALLOUT

1.1

By

Carl F. Miller

THE FORMATION PROCESS

Observation and analyses on fallout particles from past tests of nuclear weapons indicate that two general types of particles are formed in near-ground detonations: (1) glasses, and (2) crystals.[1,2,3] The latter type usually consisting of a group of soil grains sintered to varying degrees of hardness. In such detonations only a small percentage of the soil that is eventually entrained by the fireball and rising cloud is initially vaporized. The fallout formation process begins when the fireball has cooled to about 3000^{o}K starting with condensation of the vaporized soil and the least volatile radionuclides to form very small liquid droplets. Within a few tenths of seconds, most of these particles disappear through coalescence with larger melted soil particles entering the fireball. A few of these small particles escape to form world-wide fallout or to collide later with, and become attached to, other larger unmelted particles.

The larger glassy particles, formed from vaporized and melted soil material, are entrained in the fireball before it cools to the melting point of the soil. During this time, the larger melted particles not only collide and coalesce with the smaller liquid soil droplets, but serve as a condensation media for other vaporized condensable fission products. The crystalline particles, entering the fireball after it has cooled to temperatures less than the melting point of the soil material, collect only late-condensing fission product radionuclides on their surfaces in addition to intercepting a few of the small vapor-condensed particles. The late-condensing fission products consist mainly of the volatile elements such as Sb, Te, and I, and the daughter products of rare gases such as Rb and Cs.

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1. Miller, Carl F., Fallout and Radiological Countermeasures, SRI Project No. MU-4021, January 1963
2. Heft, R., Private Communication, Lawrence Radiation Laboratory, Livermore, California, January 1966
3. Miller, Carl F., and P. D. LaRiviere, Introduction to Long-Term Biological Effects of Nuclear War, SRI Project No. MU-5779, April 1966

As a consequence of the above described process, the more refractory fission product radionuclides are concentrated in the glassy particles. In the smaller glassy particles, these radionuclides are distributed fairly uniformly throughout the particle volume; in the larger glassy particles, many of which have unmelted centers, the radionuclides are concentrated in the peripheral glassy layer. Thus, the specific activity of the glassy particles is more or less constant for the smaller particles and approaches an inverse function of particle diameter as the particle diameter becomes large. The specific activity of the more volatile radionuclides that deposit on the surface of the unmelted (and apparently constitute a minor part of the radioactivity carried by the smaller melted particles), tends to vary inversely with particle diameter.

The derived specific activity of the local fallout from Shot SMALL BOY, a low-yield device detonated near ground surface at the Nevada Test Site, is shown as a function of particle diameter in Figure 1. The low values of the specific activity for the smaller particles resulted from the unavoidable presence of extraneous local dust particles in the collected samples. Although not shown in the figure, small particles in the sub-sieve range (i.e., diameters less than 40 microns) were found in all local fallout samples. They arrive attached to the larger particles, or fall in the wake of the larger particles, or are formed in the sieving process through breakage of loosely sintered particles. For the Shot SMALL BOY fallout, the contribution of these smaller particles in the local fallout area to the total radioactive content ranged from 5 to 10 percent.

The curve of Figure 1 may be represented by:

$$C = \frac{3.5 \times 10^{18}\left[1 - e^{-6.9 \times 10^{-4} d}\right]}{d}, \quad d = 50 \text{ to } 4{,}000 \text{ microns} \qquad (1)$$

where d is the particle diameter in microns and C is in fissions per gram. The range in d indicates that essentially all of the radioactive particles falling in the local fallout area were greater than 50 microns and that essentially none were found larger than 4,000 microns. The form of Equation 1 and the numerical coefficient values indicate that the gross radionuclide content of the particles is essentially proportional to particle volume or weight for particles with diameters between about 50 and 200 microns. For particles with larger diameters, the radionuclide content becomes increasingly concentrated on the surface of the particles and at diameters of about 2000 microns and larger, the radionuclide content is essentially proportional to

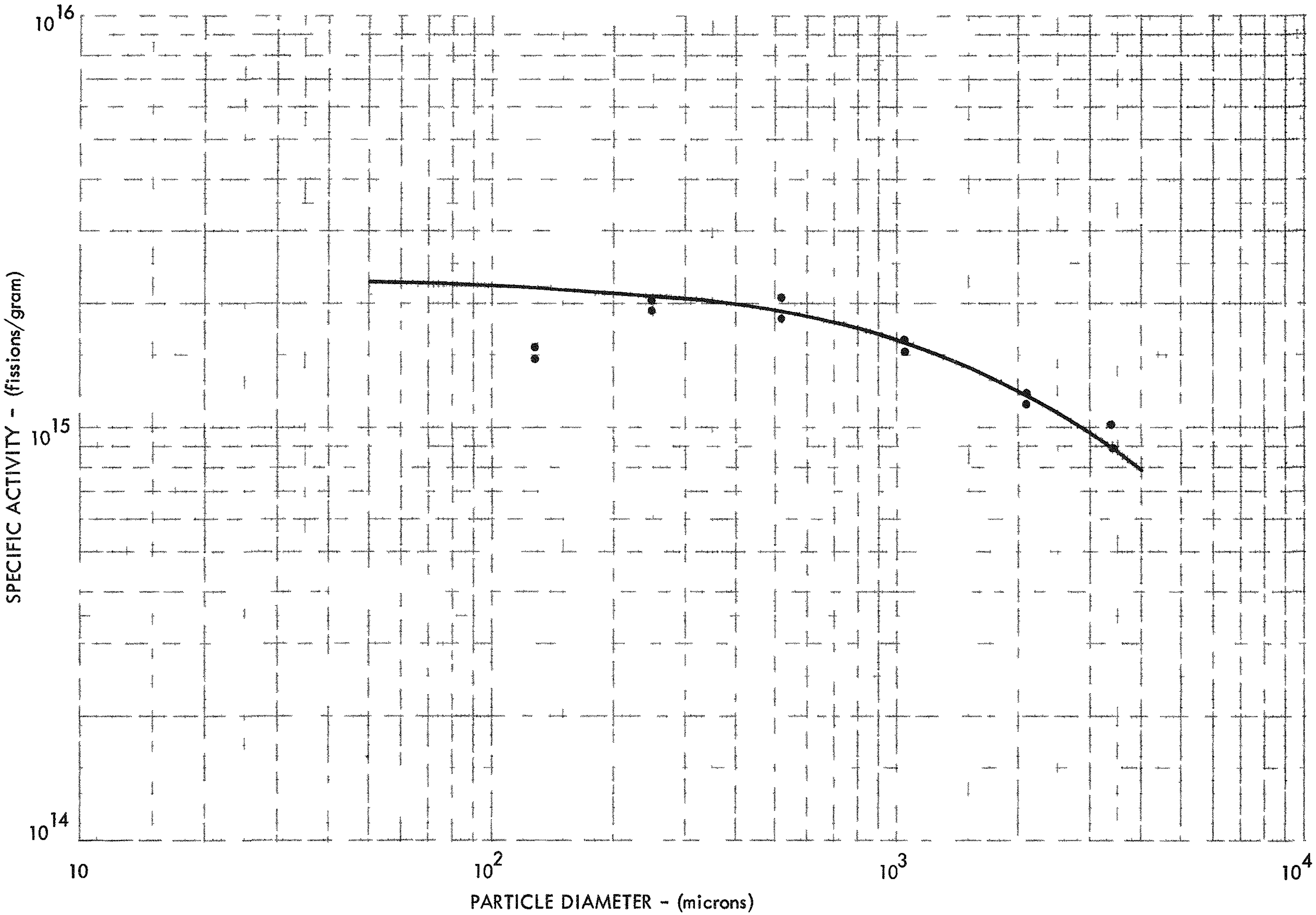

Figure 1. Variation of Estimated Specific Activity With Particle Size For Shot Small Boy.

surface area (i.e., to 1/d). The specific activity of the smaller particles would be expected to be larger than the limiting value of Equation 1 and should increase somewhat as the diameter decreases below about 50 microns.

The major significance of the two-stage fallout formation process, aside from the resulting bimodal particle type composition, is that the radionuclides that condense into the liquid droplets in the first stage become immobilized with regard to latter contamination of water and cycling in food chains; but the radionuclides that condense in the second stage on the surfaces of the particles may not be permanently immobilized and do become involved in later biochemical processes.

The relative amount of the surface-condensing soluble nuclides would tend to be reduced by a lower melting point soil and a higher explosion yield; the soluble nuclide concentrations, alternatively, should be increased by a higher melting point soil and a lower explosion yield.

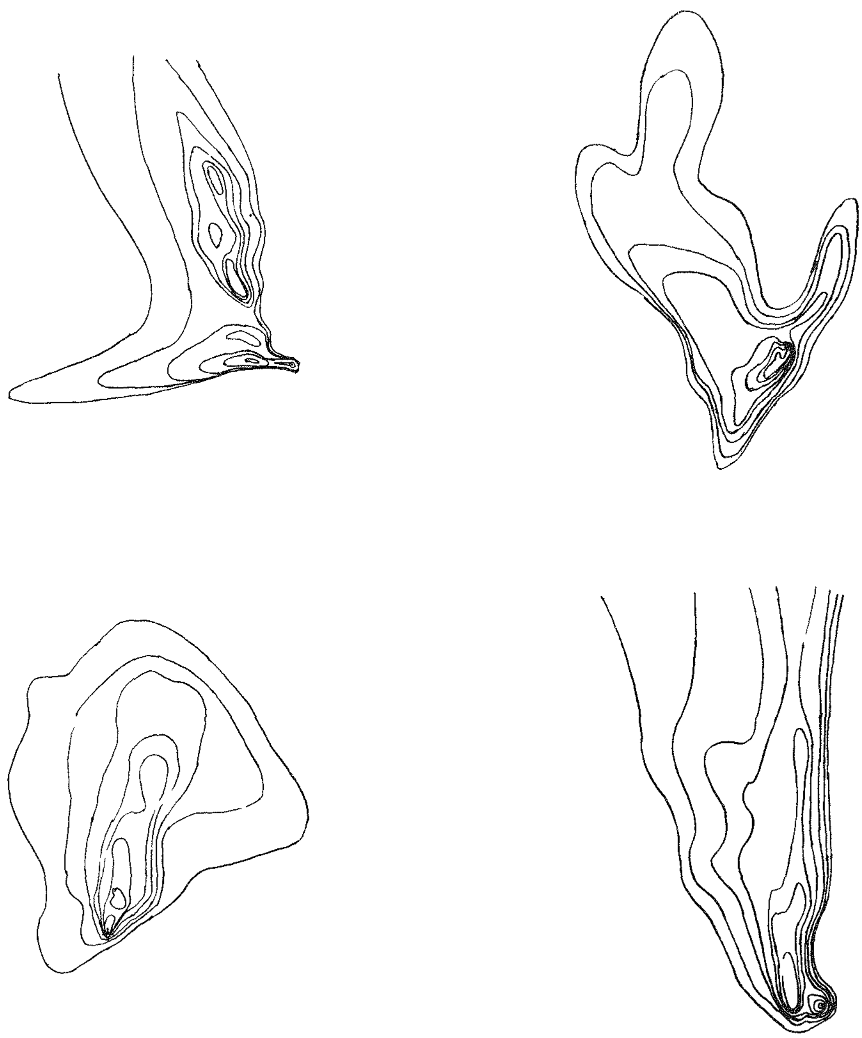

Figure 2. Example Representations of Observed Fallout Patterns.

THE DISTRIBUTION PROCESS

As the fireball cools and rises into the atmosphere, toroidal circulations take place. This circulation apparently concentrates the remaining gaseous radionuclides and smaller particles in the center of the toroid and, due to the downward flow of air at the periphery, accelerates the falling out of the larger particles. Thus, the time of arrival of the largest fallout particles is usually less than is estimated on the basis of free fall from the bottom of the cloud. In addition, some degree of oscillation of the hot gas bubble occurs as it rises and cools. The circulation is rapidly damped after transition to cloud form (indicated visually by the condensation of water vapor) after which the system degenerates into fragmented turbulent regions. Shortly thereafter, normal atmospheric forces begin to predominate and the cloud is gradually dispersed and dissipates its remaining energy in continued lateral expansion.

The tropopause has no significant affect on the cloud height or its rate of rise except for clouds that have maximum heights that coincide with the tropopause. The time of cloud top height stabilization varies almost inversely with explosion yield such that cloud tops from large explosion yields reach their maximum height at much shorter times than do those from smaller explosion yields. The bottom of the cloud and especially the cloud radius do not "stabilize" in space at any time but continue to increase until the cloud, as a distinct visible form, breaks up or disappears.

Combination of the circulation, oscillation, turbulent fragmentation, and, perhaps, unsymmetrical explosion geometry result in a nonuniform particle and radionuclide distribution in the visible cloud volume. The nonsymmetry of these distributions within the volume apparently occurs in both the vertical and horizontal directions. As a consequence, the resulting fallout patterns are more highly dispersed and fragmented than can be accounted for on the basis of horizontal wind shear, diffusion, and vertical motions in the atmosphere. Examples of some fallout patterns illustrating these points are shown in Figure 2. Several of the composite patterns appear to have resulted from a group of individual particle clouds.

The major factors, however, in the fallout particle distribution over the landscape from the cloud sources are the wind speeds and directions at all altitudes and the falling speeds of the particles. Of the two, the latter are usually known to a considerably greater accuracy than are the wind speeds and directions in spite of the fact that particle densities are variable and that the shape factors for the irregular or angular particles are not known with a great deal of precision.

THE DEPOSITION PROCESS

Very little direct information on details of the deposition process for local fallout has been obtained from field tests of nuclear weapons. The bulk of the currently available information in the United States has been derived from observations in Costa Rica on the behavior of the fallout particles produced by explosive eruptions of Volcano Irazú in 1964 and 1965.[4,5,6] This source of information is particularly applicable to inhabited urban and rural areas and was readily obtainable because the particles were nonradioactive.

Fallout depositions that occur during the night where the surface wind speeds are very low and the relative humidity is quite high are found to be uniform on all exposed surfaces, approaching the "ideal" deposit conditions assumed in most dose and shielding calculations. This type of deposit is illustrated by Figure 3 showing a layer of particles on a street and a box top. The effect of wind in moving such deposits from smooth-surfaced roofs and streets within a period of several hours is shown by the redistributed patterns of Figure 4 for roofs and streets. These views indicate how the particles drift into depressions and wind-protected locations. Such movement does not occur on rough unpaved surfaces such as lawns and fields, or on wind-protected surfaces, as is illustrated by Figure 5.

The irregular distributions shown in Figure 4 for paved areas and roofs are typical of the original deposits that occur in the daytime under dry conditions with wind speeds of 5 mph or greater. These deposition patterns are far from the ideal case and, in the case of radioactive fallout, would

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4. Miller, C. F., The Contamination Behavior of Fallout-Like Particles Ejected by Volcano Irazú, SRI Project No. MU-5779, April 1966

5. Miller, C. F., and Hong Lee, Operation Ceniza-Arena: The Retention of Fallout Particles from Volcano Irazú (Costa Rica) by Plants and People; Part One, SRI Project MU-4890, January 1966

6. Miller, C. F., Operation Ceniza-Arena: The Retention of Fallout Particles From Volcano Irazú (Costa Rica) by Plants and People; SRI Project No. MU-4890, Part Two, December 1966; and Part Three, December, 1967

result in hot spots and clean spots in urban area configurations. The overall effect would be to decrease the average gamma radiation levels relative to the ideal case. Radiation contributions from roof sources would be reduced the most, and the radiation levels at centers of paved areas would also be considerably reduced. On the other hand, radiation contributions from sources on grassy areas near buildings with sloped roofs and in gutters (on both roofs and streets) would be increased.

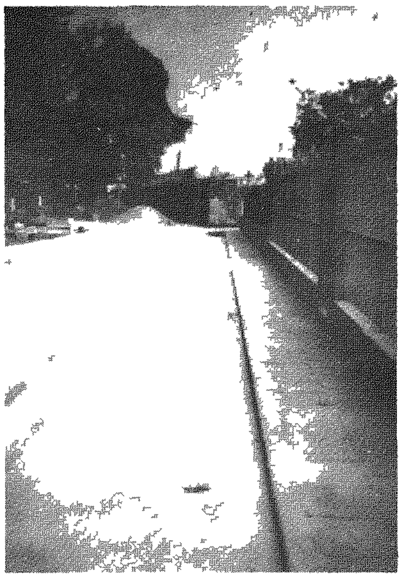

Figure 3. Particle Deposit on Street and Box Top Under Calm Wind Conditions.

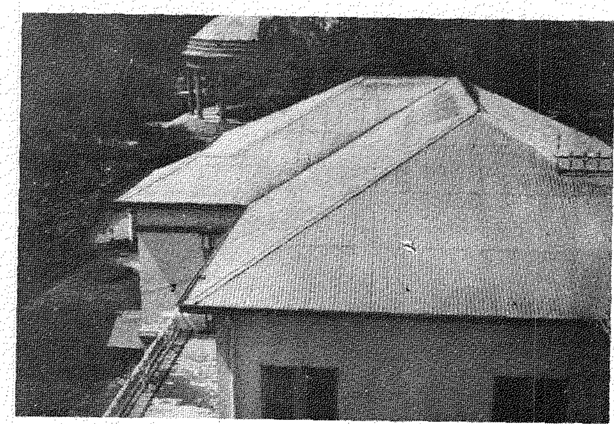

Figure 4. Redistributed Particles or Particle Depositions on Paved Areas and Smooth, Sloped Roofs Under Moderate Wind Speed Conditions.

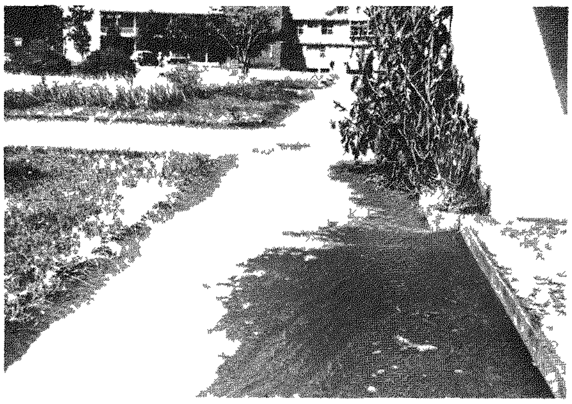

Figure 5. Particle Deposition and Redistribution or Accumulation on Lawns and Wind-Protected Locations.

The retention of fallout particles by plant foliage is a fairly complicated process depending mainly on the size and shape of the plants, plant spacing and density, wind speed, particle fall angle (i.e., particle size), exposure time, rainfall, humidity, and plant growth rates. With a few exceptions, the surface characteristics of the foliage is a second order variable. The dependency of the retention on several of these variables is illustrated below by the data obtained in Costa Rica[6] for the cereal grains barley, oats, and wheat, and for a small camphor tree.

The ratio of the weight of particles initially retained by the foliage to that deposited on a horizontal surface (often erroneously called the fraction retained) for the cereal grains in grass form is given by

$$F_L = 0.023\ w_L\ (\alpha + 1)e^{-0.118\ \bar{v}_w},\ \text{dry and damp} \qquad (2)$$

where w_L is the dry weight of the grass per unit area, α is the ratio of the average wind speed to the average particle falling speed (and is equal to cot φ where φ is the angle from the horizontal to the average particle fall trajectory in the direction of the wind), and $\bar{v}_w$ is the average wind speed over the deposition period. In Equation 2, F_L is directly proportional to the density of the grass and decreases exponentially with increasing wind speed; for very low wind speeds and large particles (i.e., large falling speeds), the value of F_L approaches $0.023\ w_L$, and for high wind speeds and very small particles, the value of F_L approaches infinity.

The values of F_L for the headed grain stalks are represented by

$$F_L = \eta_o\ n_{xy}\ m_p^{2/3}\ (\alpha_o^o - \alpha),\ \alpha < \alpha_o,\ \text{dry and damp} \qquad (3)$$

and

$$F_L = \eta_o'\ n_{xy}\ m_p^{2/3}\ \alpha,\ \alpha \geq \alpha_o,\ \text{dry and damp} \qquad (4)$$

The general equation for representing F_L for the near-ripened grain heads is

$$F_L = \eta_o\ n_{xy}\ m_p^{2/3}\ \alpha\ e^{-b\bar{v}_w},\ \text{dry and damp} \qquad (5)$$

where η_o (or η_o') is a screening coefficient, n_{xy} is the average number of stalks (or heads) per unit area of ground surface, m_p is the average dry weight per stalk (or head), α_o^o is a constant giving the intercept value of α at zero F_L, α_o represents a characteristic leaf angle where a minimum in F_L occurs, and b is a constant accounting for a decrease in the screening coefficient with wind speed. The derived values of the constants of Equations 3, 4, and 5 are summarized in Table 1. The characteristic leaf angles (or particle trajectory angles) where a minimum of retention occurs is about 37, 33, and 31 degrees for barley, oats, and wheat, respectively. The observed ratios, $F_L/(n_{xy}\ m_p^{2/3})$, designated as $F(\varphi)$ for the whole grain stalks are plotted as a function of α in Figure 6, in which the indicated minimums in F_L are clearly shown. The dependence of the ratios, $F(\varphi)/\alpha$, for the grain

heads on wind speed is illustrated by the data plotted in Figure 7. A similar dependence of the screening coefficient on wind speed for the data from the whole stalks was not exhibited by the data; apparently the lower leaves tend to retain the particles not retained by the grain heads at the higher wind speeds. The equations indicate the large range in F_L that is possible depending on the values of n_{xy}, m_p, α, and $\bar{v}_w$.

The total weight of particles retained by the leaves of the small camphor tree with a near spherical shaped canopy (radius of about 3 ft and height of 10 ft) is represented by

$$\Delta M_t = \frac{\eta \pi a^2 \Delta m}{\sin \varphi} \qquad (6)$$

where a is the radius of the canopy and Δm is the weight of the particles deposited per unit area in a nearby unprotected horizontal surface. However, the weight of particles ΔM_t, is not distributed uniformly throughout the canopy but is concentrated on the upper portion of the canopy facing the wind. Particle flux measurements and leaf sampling data indicate that the particle flux within the canopy can be represented by

$$\Delta m(r) = \Delta m \; e^{-\beta r} \qquad (7)$$

where $\Delta m(r)$ is the particle flux at the distance r from the peripheral leaves along a line parallel to the average particle trajectory, and β is a coefficient whose value depends on wind speed and the volume density of the leaves through

$$\beta = (\rho_L/\bar{v}_w)\; \beta^o \qquad (8)$$

in which β^o is a constant whose value depends on the leaf form and, perhaps, the leaf surface characteristics. The deduced value of β^o for the camphor tree is 0.061 (mi/hr)/(gm/sq ft) for $\bar{v}_w$ in mi/hr and ρ_L in gm/cu ft; the value of ρ_L for the camphor tree was estimated to be 13.6 gm/cu ft. Integration of the particle flux of Equation 7 over all path lengths through the spherical canopy gives the effective value of η of Equation 6; it is

$$\eta = 1 - \frac{1}{2a^2\beta^2}\left[1 - (2a\beta + 1)e^{-2a\beta}\right] \qquad (9)$$

Similar integrations are not possible for other canopy shapes. For this tree, the observed values of η averaged about 80 percent of those calculated from Equation 9, indicating a slightly larger reduction in retention due to wind effects than that included in Equations 7 through 9. The leaf contamination gradient within the canopy is described by Equation 7.

The fraction of the retained particles not removed by wind and rain weathering is represented by

$$F_{NR} = \frac{\left[f_R \psi_{wr} + f_{NR}\right]}{G} \tag{10}$$

in which f_R is the removable fraction of the particles, f_{NR} is the fraction not removable by wind and rain effects, G is a fractional plant growth factor, and ψ_{wr} is a weathering which is usually specified as ψ_w for wind weathering only and as ψ_r for removal of particles by rain only. The derived mathematic form for representing the weathering data are

$$\psi_w = e^{-k_w \tau} \tag{11}$$

and

$$\psi_r = \frac{\psi_r^o \, e^{-k_r R}}{R} \tag{12}$$

in which k_w is a constant for each plant type, τ is the integrated wind speed over the weathering period (i.e., equal to $\bar{v}_w t$ if $\bar{v}_w$ is the average wind speed and t is the time after deposition), ψ_r^o and k_r are constants, and R is the amount of rainfall in a given shower. The value of f_{NR} is estimated from

$$f_{NR} = C^o_{PNR}/C^o_p \tag{13}$$

where C^o_p is the initial concentration of particles on the foliage and C^o_{PNR} is the concentration of particles not removed by a relatively high pressure water sprayer. The evaluated weathering equation constants for the three cereal grains and the camphor tree leaves are summarized in Table 2. The variation of $\ln\psi_r R$ with R for the cereal grains (including rye) is shown in Figure 8.

The above representations of the contamination of vegetation by airborne particles form the basis for evaluating the beta and gamma dosages that plants may receive from fallout and, to some degree, the input information for the entry of radionuclides in several food chains. In most cases, the entry into food chains from foliar contamination at early times would predominate over that by entry from the soil through the root systems of plants. The latter mode of entry would tend to become relatively more important in the long term.

Data on personnel contamination are rather scarce but the few data available indicate that hair retains particles with a fairly high degree of efficiency. The representation of the ratio of the weight of particles retained by hair (modeled as 1/2 of a sphere) to the deposit density on a horizontal surface, a_h, is given by

$$a_h = \eta_h \frac{\pi a^2}{2} \frac{(1 + \sin \varphi)}{\sin \varphi} \tag{14}$$

where η_h is the impaction-retention coefficient for hair and a is the effective radius of the head. The variation of observed values of η_h with τ (i.e., $\bar{v}_w t$) is shown in Figure 9 for two types of hair cuts. The lines in the figure are represented by

$$\eta_h = 2.2\ e^{-0.078\tau} \tag{15}$$

for the crew cut, and

$$\eta_h = 1.3\ e^{-0.078\tau} \tag{16}$$

for the medium cut.

SUMMARY

The general nature of fallout particles has been discussed briefly in terms of the processes leading to their formation in the nuclear fireball and rising cloud. Inhomogeneities in the clouds are given as a reason for the dispersion and fragmentation in the observed fallout patterns. Most attention has been given to details of the deposition processes and the behavior of the fallout particles during and after their contact with exposed surfaces with emphasis on the interception and retention of particles by plants.

Table 1

SUMMARY OF INITIAL RETENTION EQUATION PARAMETER VALUES
FOR BARLEY, OATS, AND WHEAT

Plant Type	Whole Stalks				Heads	
	η_o	η'_o	α_o^o	α_o	η_o	b(hr/mi)
Barley	0.0181	0.00519	1.729	1.344	0.00683	0.191
Oats	0.0153	0.00503	2.053	1.544	0.00531	0.210
Wheat	0.0188	0.00472	1.669	1.344	0.00574	0.233

Table 2

SUMMARY OF AVERAGE VALUES
OF FOLIAR CONTAMINATION WEATHERING EQUATION PARAMETERS
FOR CEREAL GRAINS AND CAMPHOR TREE LEAVES

Plant	k_w (mi^{-1})	σ_w (%)	ψ_r^o	σ_r (%)	k_r (mi^{-1})	C^o_{PNR} (gm/gm)	σ_c (%)
Grass (barley)	0.0682	22.0	0.0260	94.5	0.399	0.0298	43.6
Grass (oats)	0.0652	51.4	0.0180	99.6	0.399	0.0298	12.1
Grass (wheat)	0.0640	55.3	0.0374	79.3	0.399	0.0314	58.0
Barley (stalks)	0.0370	7.8	0.0554	75.5	0.995	0.126	24.1
Barley (heads)	0.0472	147.7	0.0408	43.0	0.864	0.104	38.0
Oats (stalks)	0.0458	44.2	0.0570	27.0	0.995	0.0482	25.4
Oats (heads)	0.0669	74.0	0.00837	32.3	0.0	0.0109	28.7
Wheat (stalks)	0.0310	30.7	0.0472	64.1	0.995	0.0371	74.9
Wheat (heads)	0.0674	77.8	0.0268	20.6	0.864	0.0565	58.4
Camphor	0.0255	22.6	0.0433	19.1	1.07	0.0181	27.2

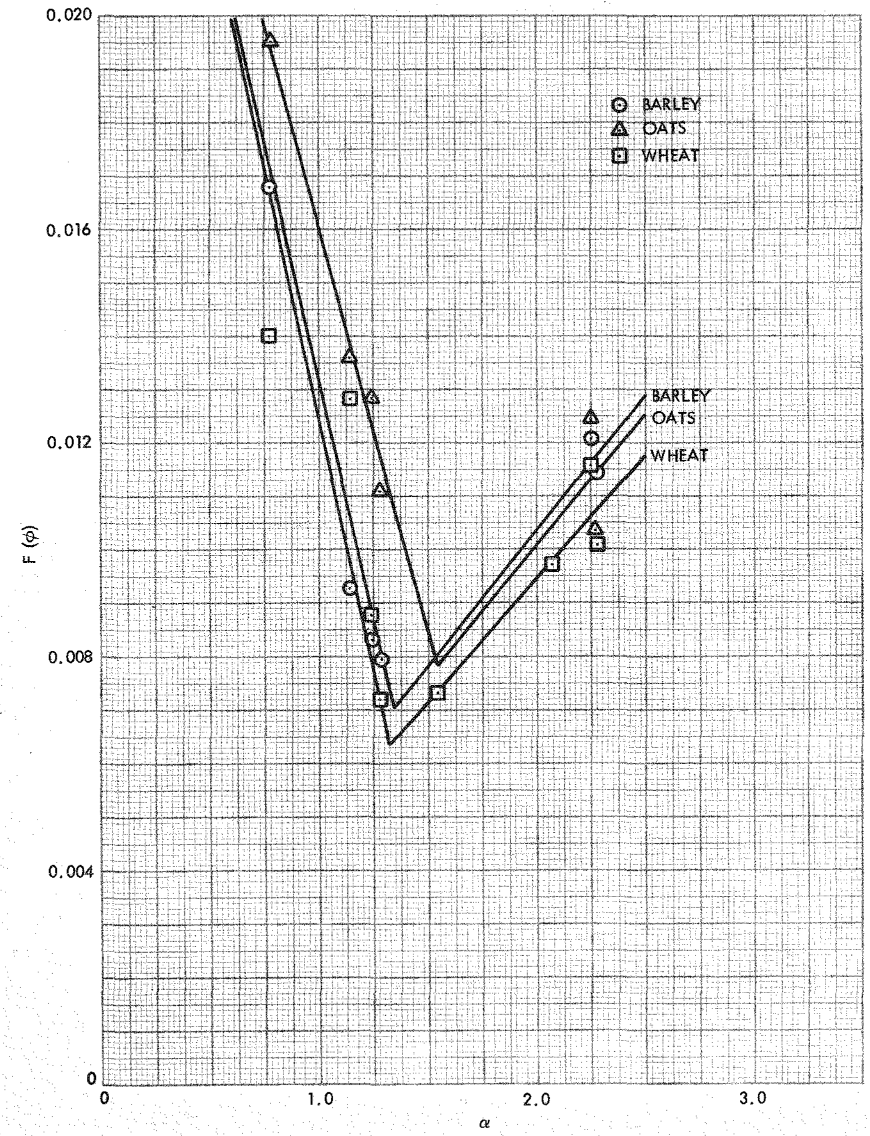

Figure 6. Variation of F(φ) With α For Barley, Oat, and Wheat Stalks.

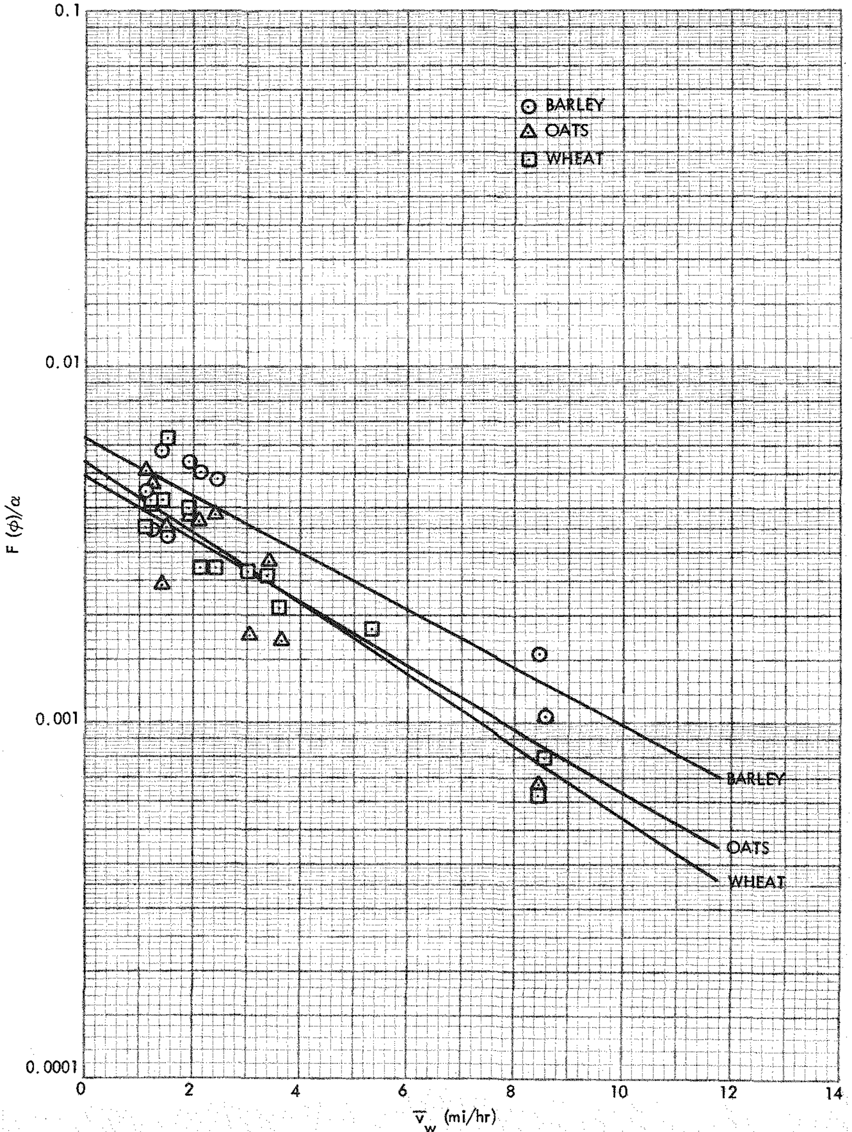

Figure 7. Variation of F(φ)/α With Wind Speed For Barley, Oat, and Wheat Stalks.

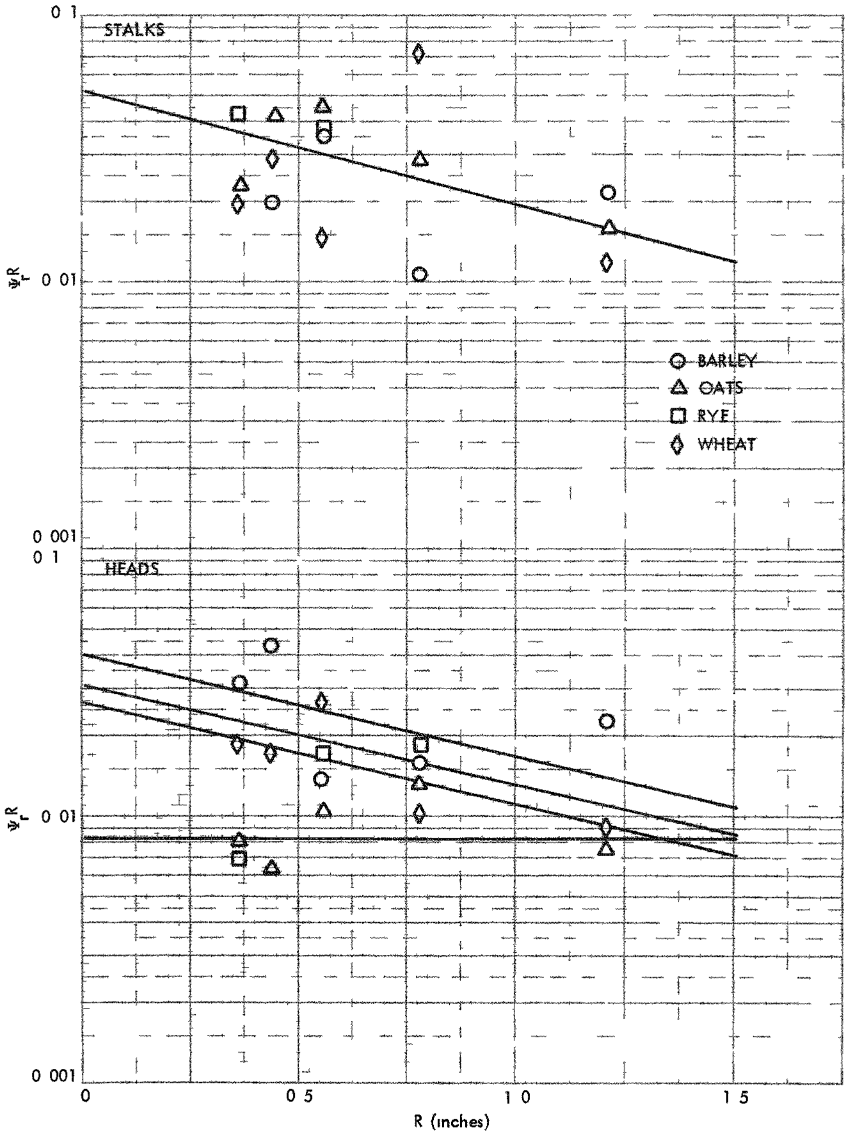

Figure 8. Variation of $\ell n\ \psi_r R$ With R For Grain Stalks and Grain Heads.

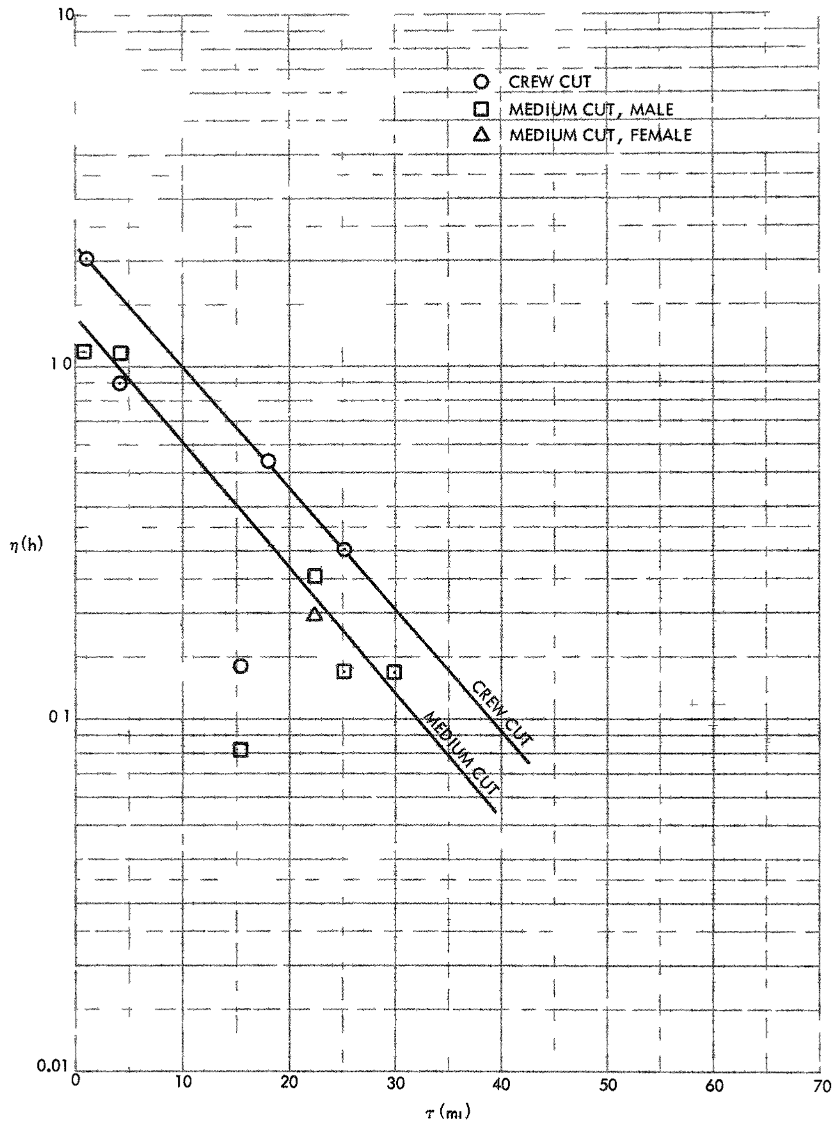

Figure 9. Variation of η_h With τ.

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BASIC CHARACTERISTICS OF NUCLEAR RADIATION FROM FALLOUT

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Definition of the Terminology

Fallout is of considerable interest in radiation protection problems because many nuclear processes of short time duration such as nuclear weapon detonations and nuclear reactor excursions cause radioactive debris to be thrown into the air, ultimately to settle into an area different from that at which the nuclear process occurred. In the strictest sense the word fallout is technically correct only if used to refer to debris that has been deposited on the earth after being airborne, but in current practise the word is used interchangeably to refer both to particulate matter that is aloft and to matter that has been deposited on the surface of the earth. Depending on the conditions of formation, fallout from nuclear weapon detonations ranges in texture from an aerosol to granules of considerable size. The aerodynamic principles governing its deposition are the same as for any other material of comparable physical nature that is thrown into the air, such as volcanic ash or particles from chimneys. However, the radioactivity found in fallout produced by processes involving nuclear fission and nuclear fusion has caused the public generally to associate the name fallout only with this particular type of deposited debris. This very special usage of the word fallout is continued in this review in which, with or without any modifying clause, it refers only to the airborne or deposited debris produced by nuclear processes of short time duration, primarily nuclear weapon detonations.

Ionizing Radiations Resulting from a Nuclear Weapon Detonation

If a weapon depends on fission to develop its energy, radiations consisting of neutrons, beta particles, and gamma rays can be expected. Neutrons are boiled off immediately after the fission fragments are formed and possess an energy spectrum that can be approximated by a Maxwellian-type distribution.[1,2] Following neutron emission most fission fragments undergo further deexcitation by emission of gamma rays. Most of the prompt photons result from a deexcitation process with a half life of about 10^{-11} seconds,[3] but a small component (about 5.7%) is delayed, with a half life of about 10^{-7} seconds,[4] and a few continue to be emitted at an observable and steadily decaying rate for times as long as 10^{-3} seconds after fission.[5,6] Because they are released in so short a time, neither prompt neutrons nor prompt gamma rays are ever a part of a fallout radiation field. They, therefore, are not considered further in this discussion. However, considerable quantities of information about them are available.[7]

The nuclear fragments that remain after release of the prompt radiations still are not stable, but contain an excess of neutrons. To reach stability they undergo beta decay, which is accompanied by gamma radiation[5] that can be used to measure many characteristics of the beta-decay process following fission, and even a few delayed neutrons.[8] The half-lives of the radioactive nuclei are of course those associated with the beta-decay processes and depend on the transition energy, which is related to the magnitude of the neutron excess (sometimes called the distance from the line of stability).

About 10^{-3} second after fission the rate of emission of prompt radiations becomes sufficiently small to be unobservable. A reasonably constant rate of decay of beta-decay-produced gamma rays is then found until about 10^{-1} second after fission. After this time enough fragments have undergone beta decay to cause a general shift of the fragment population toward the line of stability, with the result that the average energy of decay is lowered and the average half-life lengthened. As a consequence, a continuing decrease in the rate of emission of ionizing radiation occurs after the initial relatively constant rate. A theoretical basis for this type of decay was first established by Way and Wigner.[9] They determined that the rate of radiation emission at early time $\underline{t}$ should be described by an equation of the form $\underline{a} - \underline{bt}$, where $\underline{a}$ and $\underline{b}$ are constants, but after several minutes the rate of emission of radiation can best be described by a single $\underline{t}^{-1.2}$ term. Such a time-dependent law to describe the decay of fission-induced radioactivity has been found from experiments to be generally valid, but to have many differences in detail,[10] as observed in the experimental results of neutron-induced fission[5,10] of ^{235}U and of photon-induced fission[6] of ^{235}U and ^{232}Th.

Fisher and Engle[11] have measured the spectral characteristics and relative intensities of the fission-product gamma rays at selected times between 0.2 second and 45 seconds following fast-neutron fission of a number of nuclides and Peelle _et al._[12] at times between 1.7 seconds and 1500 seconds following thermal-neutron fission of ^{235}U. Bunney and Sam[13] overlap and extend to three days the work by Peelle _et al._ in their measurements of the spectra of gamma radiations emitted by the fission fragments following fast-neutron fission of ^{235}U and ^{238}U. The results found by Bunney and Sam are in reasonably good agreement with those of Peelle _et al._ in the overlapping time interval of 15 to 16 minutes following fission. Peelle _et al._ find that the intensity of the fission-product radiation, measured as photons MeV^{-1} $fission^{-1}$ sec^{-1}, at 200 seconds after fission is about 1/100 the intensity at 1.7 seconds after fission, in general agreement with predictions. Fisher and Engle's results also indicate that the rates of decay agree with theory.[5] Thus more than 99% of the fission-product gamma rays are emitted within the first three minutes following fission. Since the radioactive material is still distributed within a mushroom cloud at three minutes after a near-surface burst of a nuclear weapon, none of the ionizing nuclear radiations emitted by the fission fragments prior to that time can ever appear to be emitted by the fallout from the burst. Because of the time required for radioactive debris to begin to be distributed in significant quantities, only those radiations emitted by fission products more than several minutes old are significant in the fallout problem. Thus, only a very small fraction of 1% of all the fission-product photons will ever appear as fallout radiation, the exact amount depending on the time required for the radioactive debris to settle to the earth in the vicinity of the detonation.

Calculations have been made[14,15] of the gamma-radiation spectra from fission-product radioactive nuclides for times ranging from a few minutes to several years after slow-neutron fission of ^{235}U, based on fission-yield calculations of Bolles and Ballou.[16]

Radioactivity may also be produced by neutron interactions within the weapon itself. In many weapons the primary radiation of this type is ^{239}Np (half-life, 2.3 days) produced by the reaction $^{238}U(n,\gamma)$ $^{239}U(\beta)$ ^{239}Np because of the presence of ^{238}U (see pp. 1690-91 of reference 17). The nuclide ^{239}U decays with a half-life of only 23.5 minutes so usually is not observed in significant amounts in fallout measurements.

Other materials besides uranium can be introduced into the regions surrounding the active portions of a nuclear weapon. These materials are then subjected to a tremendous neutron flux density when the weapon is detonated, with the result that many radioactive nuclei are formed. At one time the hazards produced by gamma radiations of a so-called cobalt bomb were discussed extensively. Based on what he considered reasonable assumptions, Dunning[18] calculated the residual-radiation exposure and exposure rate that one could expect from a one megaton nuclear weapon, containing cobalt, that derived half of its energy from fission and half from fusion. His conclusions are that the effect of the cobalt is almost insignificant at very early times but it becomes appreciable after several days. For example, his calculations indicate that one hour after detonation the gamma-ray exposure rate produced by the fission products is about 5.9×10^5 times the exposure rate produced by the ^{60}Co gamma rays, but after 30 days the fission-product exposure rate is only 0.02 times the ^{60}Co exposure rate. An infinite time extrapolation shows the contribution to the total-exposure by fission-product radiations and by ^{60}Co radiations to be approximately equal. Radiations emitted by long-lived neutron-induced activities, such as those from ^{60}Co, are delayed considerably compared to fission-product radiations. For example, almost 100% of all photons emitted by a source of ^{60}Co are emitted more than three minutes after the source is produced. As a result, the percentage of the total radiation hazard associated with fallout from a detonation of this type would be much greater than from a detonation in which the only sources of residual radiations are the fission-product radioactive nuclides.

The technical possibility also exists that all neutron-induced activities are short-lived, such that the overall effect is opposite to that described for ^{60}Co, and would lead to greatly reduced amounts of long term radioactivity in any fallout that is produced. A significant reduction per kiloton of weapon yield is also found in the long-lived radioactivities of local fallout if a nuclear weapon has a sufficiently high fusion/fission ratio.

Comparison of Fallout and Fission Product Gamma-Ray Spectra

Cook[19] has compared calculations by Nelms and Cooper[15] of expected gamma-radiation spectra from radioactive fission-product nuclides with measured gamma-ray spectra of fallout samples. These comparisons indicate that there is a reasonably close resemblance between calculation and experiment for photons with energies greater than 290 keV. However, the ^{239}Np radiations in the experimental measurements usually completely

obliterate the fission-product radiations in the energy regions between 100 and 290 keV. Differing amounts of ^{239}Np in the radioactive products of different weapons produces uncertainties in the comparison. Furthermore, fractionation, briefly discussed in a later section of this paper, greatly reduces the accuracy with which exact spectral characteristics of sources of fallout gamma radiation can be predicted.

Aerodynamic Effects

Many observed characteristics of the ionizing radiations emitted by deposited nuclear weapon debris are dependent on the way in which the debris is distributed. The detailed nature of this distribution depends on existing air currents, height of burst, weather pattern, and many other factors. After deposition, debris particles may be further moved in varying amounts, depending on the nature of the particles themselves, as well as the characteristics of the ground surface, air currents, rainfall, and other factors.

Because of the rapid expansion of the air near the point of detonation and the consequent lowering of air density, a large percentage of the material associated with the detonation is carried into a cloud having the general shape of an oblate spheroid. This cloud usually reaches a height of several thousand feet above the point of detonation if the detonation occurs reasonably close to the surface of the earth. If all particles in the cloud are assumed to be about the same shape and of constant density, the time required for them to reach the surface of the earth from some given height is a function only of particle size, the larger particles being the first to reach the surface.[20] Furthermore, if there is a prevailing horizontal shearing wind pattern to carry away particulate matter, the larger-diameter (larger-mass) particles are deposited closer to the point of detonation than the smaller-diameter particles. Because of the finite size of the cloud formed by a weapon detonation and the general distribution of particles throughout the cloud, as well as the various possible routes that a falling particle can take in returning to the surface of the earth, a range of particle sizes is found at any point downwind from a nuclear detonation. As a result, the distribution of fallout particulate matter from the cloud is roughly divided into three topographical categories called local (or close-in), tropospheric (or intermediate), and stratospheric (or worldwide) fallout.

Local fallout consists of the larger particles (often defined as those with diameters greater than 20 microns) which, because of their size, have a high rate of settling and fall within approximately 100 miles of the point of detonation. After the tremendous energy of the explosion has been dissipated, these particles fall reasonably quickly, carrying with them much of the radioactivity. Because of the large range of particle sizes in the cloud produced by a nuclear weapon detonation, and the prevailing horizontal shearing wind patterns that exist in most of the earth's atmosphere, elongated local fallout patterns are usually formed following near-surface bursts.[21-24] These regions of local fallout can usually be found by observing the gamma-radiation associated with them, such as the gamma-ray intensity contours shown in frames F through I of Fig. 1 for a 1 kt near-surface burst.[39]

Tropospheric fallout consists of particles injected below the tropopause that are a few microns in diameter or smaller. These particles continually mix through the circulating air mass of the earth and gradually settle to the ground or are brought down by rain or snow.[25-27] Parts of the tropospheric fallout may remain in the atmosphere a month or more, long enough to circle the earth several times. Stratospheric fallout consists of particles similar to those in the tropospheric fallout but which has been injected into the region above the tropopause. This material has a mean residence time of many months, for some nuclides as much as a few years, during which time it completely encircles the earth. It gradually returns through the tropopause, primarily in certain regions where mixing between the two layers is more probable than in others. In this symposium we are concerned only with problems of local fallout, so only occasionally will any further reference be made to either tropospheric or stratospheric fallout.

Detonation Conditions Needed to Form Local Fallout

Large amounts of radioactive fallout occur locally only if large quantities of material are present onto which radioactive nuclides produced by the weapon can be attached. If a weapon is detonated within a few hundred feet of a land surface, the explosion causes soil and other particles to be introduced into the fireball before condensation of the vaporized material is complete. Condensation then takes place either directly onto the surfaces of the hot oxide or silicate particles from the earth, or by a two-step process in which the vaporized materials first condense and then impact and collect onto the earth-surface materials.[28] Following an air burst, unvaporized surface materials onto which radioactive weapon debris can condense are generally absent from the fireball. The weapon radioactive debris can then combine only with naturally occurring aerosols, and is carried away as extremely tiny particles, or as gas molecules, to form only tropospheric or stratospheric fallout, except possibly in a rain-producing atmospheric region,[27] when the probability of precipitation of reasonably large quantities of radioactive debris in localized areas appears to be relatively high. If a weapon detonation takes place sufficiently far below the surface, local fallout is again absent because the radioactive materials are trapped by the surrounding earth. Thus the amount of local fallout depends on the height or depth of the detonation, as well as the weapon yield and the nature of the terrain.[29,30] The fraction of the total radioactivity going into local fallout, tropospheric and stratospheric fallout and trapped within the earth has been plotted (Fig. 2) by Nordyke[29] as a function of the ratio of the depth of burst to the depth of apparent crater for alluvium at the Nevada Test Site. A negative ratio means that the burst is above ground. He uses the word prompt to refer to local fallout and long-range airborne to refer to the combined tropospheric and stratospheric contribution.

Fractionation

Radiochemical analyses performed by Mackin *et al.*[31] on individual fallout particles from a nuclear detonation at Bikini Atoll indicate that prediction of the radiation characteristics of fallout may not be

particularly simple. Such radiochemical analyses are strongly influenced by fractionation, a term used to describe any alteration occurring between the time of detonation and the time of radiochemical analysis. Fractionation causes the radionuclide composition of a debris sample to be non-representative of the detonation products as a whole.[32,33] This process begins with the condensation of radioactive and inert material from the fireball, some radionuclides being preferentially taken up by the condensed phase. Although the chemistry of fractionation in nuclear weapon detonations is not itself a part of the problem of the ionizing radiations, the fractionation process can play a profound role in determining the types and energies of the radiations that are observed following nuclear explosions. For example, Mamuro et al.[34] note that particles enriched in ^{95}Zr + ^{95}Nb and in ^{140}Ba + ^{140}La, but impoverished in ^{103}Ru have been found in fractionated fallout from nuclear test explosions by the U.S.A., U.S.S.R., and China, but particles impoverished in ^{140}Ba + ^{140}La are not found in U.S.S.R. fallout, although such particles are found in U.S.A. and Chinese fallout. This effect is probably related to the conditions of detonation. A survey of the physical and radiochemical properties of fallout particles has been given by Crocker et al.[35]

For underwater detonations a bubble of intensely hot gases and water vapor is formed. This bubble usually breaks through the surface and its contents are distributed by the prevailing winds. Following a detonation of a device on a barge anchored in the lagoon at Bikini Atoll in water sufficiently deep that little or no material from the lagoon bottom was swept up into the fireball, Adams et al.[28] found that evaporated seawater did not condense until very low temperatures had been reached, such that the amount of condensation or vaporized solids was about the same as after an air burst.

Neutron-Induced Activities in Surrounding Materials

Besides those that are fission products, other radioactive nuclides are also formed by neutron capture in materials within a few hundred feet of the point of detonation. Radioactive nuclides produced in soil below an air burst form a gamma-radiation field in a nearly symmetrical pattern around surface zero, as illustrated in Fig. 1 (A through E) for a 1 kt air burst.[36] Generally this radiation field decays relatively rapidly because its longest-lived radionuclide, ^{24}Na, has a half-life of only 15 hours. Other radionuclides usually found in reasonable abundance are ^{56}Mn and ^{28}Al. The magnitudes of these gamma-radiation fields not only vary considerably for soils having differing chemical content but also depend on the moisture content of the soil.[7]

The effect of relative height of burst on the distribution of residual radioactivity is seen rather dramatically in Fig. 1 in which the radiation field contours of a near-surface burst, even though produced by a smaller yield device, cover a much larger area and decay much more slowly than the radiation field of an air burst, because fission-product radioactivity results from many more and longer lived radionuclides than the radioactivity induced in soils by neutrons of an air burst. However, Batzel[37] has indicated that, if a purely fission weapon were detonated underground, the neutron-induced activities one day after detonation can be as much as 25% of the total activity, as illustrated in Fig. 3, but this relative activity drops to about 1% after one week

and 0.1% after 1-1/2 months. If the detonation is above ground, the contributions from neutron-induced activity are smaller because of the smaller solid angle of earth subtended for the incident neutrons. The ratio of fission-product activity to neutron-induced activity is thus strongly dependent on detonation conditions. Neutron-induced activities in surrounding media for weapon detonations near the ocean surface are indicated by Heiman[38] to be less significant than for those near land surfaces.

Gamma Radiation from Distributed Sources

Because fallout particles from near-surface nuclear detonations are usually deposited over a reasonably large area downwind from the point of detonation, knowledge of the radiation fields produced by distributed sources is important in any consideration of the effects of fallout. For calculational purposes an ideal distributed source would be planar, of infinite extent in the direction of the plane, uniformly distributed and infinitesimally thin. In reality, however, the distribution is seldom very uniform. Furtherfore, wind and rain cause the fallout particles to settle into intersticial regions of the ground surface because most exposed soil surfaces are usually relatively rough. These particles are often covered by dust or blocked from view by the numerous minute vertical projections of the surface. The result is that ionizing effects from beta radiation extends, at most, to a few centimeters above the surface, and often not even that high. The gamma radiations emitted by the radioactive particles are modified by the attenuation properties of the intervening earth and air between source and detector. The characteristics of the radiation above such a distribution of radioactive source material are thus a combination of scattered and direct gamma radiation. If the interstices on the earth's surface are small, relatively close together and randomly spaced, a gross investigation of a few square meters of surface area should reveal an apparent uniform distribution of radioactive fallout particles, even though a microinvestigation reveals quite large non-uniformities.

To arrive at a realistic estimate of the dosimetric effects of a distributed source of fallout particles has required a series of different types of calculations and experiments, some of which are reviewed in the following paragraphs.

Calculated Radiation Fields

Measurements and calculations mentioned earlier in this paper have been concerned primarily with the basic physical characteristics of the gamma-radiation from fallout, such as number or photon spectra and generally with good-geometry measurements. On the other hand, radiation hazard from fallout must be related to exposure spectra, which indicate the exposure rate (air ionization per unit time) associated with the photons in each energy interval. Also the radiation is incident on a subject from a number of directions, not a good-geometry situation. Two steps are necessary to relate photon spectra to exposure spectra. First, an energy spectrum, which gives the total energy of all photons emitted per unit time within each energy interval, must be derived by multiplication of the number spectrum and the mean energy of each energy interval.

Next, to derive the exposure spectrum, the energy spectrum is multiplied by the energy absorption coefficient for air for each energy interval. Finally, both the effect of the absorbing material between source and detector, as well as the physical distribution of the source must be considered. In fallout applications the source is generally considered to be planar and the detector to be about 3 feet (approx. 1 meter) above the plane of the source.

A number of calculations have been made of the radiation field produced in air above a planar, infinitesimally-thin gamma-ray source, both for sources of infinite extent and for sources having specific geometrical shapes, such as rectangular or circular plaques. These calculations for surfaces of specific shape and size have usually been made to assist people engaged in shielding research who must consider situations in which there is fallout on areas of finite size, such as building roofs and areas between buildings. Most calculations are useful only for determining the radiation field to be expected in specific geometrical arrangements and each problem must be solved individually. A comprehensive documentation of work of this type is given in reference 39.

Crocker et al.[40,41] have calculated what they call exposure-rate factors for gamma-ray emitting radionuclides produced by fission of uranium and plutonium, as well as comparable factors for a number of neutron-induced radioactivities that are sometimes found in weapon debris. This factor, expressed in units of [R/hr] / [(disintegrations/sec)/cm^2], is derived for an exposure-rate in air three feet above the idealized situation of a non-absorbing plane of infinite extent uniformly contaminated with the nuclide in question, emitting radiation at the rate of one photon per second per cm^2 of contaminated plane. In Appendix III of reference 42, Taylor estimates that 1.0 μCi/cm^2 of fallout radioactivity on an infinitestimally thin, planar surface gives an exposure rate of approximately 0.1R/hr three feet above the surface. This rate corresponds to an exposure-rate factor of 2.7×10^{-6}, which is in reasonably good agreement with an appropriate mixture of the exposure-rate factors of the various radionuclides considered by Crocker et al. Those radionuclides that emit higher energy photons, such as ^{140}La, have larger exposure-rate factors, which means that smaller amounts of these radionuclides are required to produce the same exposure rate. Using their earlier experimentally determined fission-product spectra[13] Bunney and Sam have calculated[43] the exposure rate three feet above a smooth plane uniformly contaminated with unfractionated products of the fast-neutron fission of ^{235}U. Their results are shown in Fig. 4. Comparisons with calculations using the results of Crocker and Turner[41] indicate that, for photons between 0.7 and 4.0 MeV, the two techniques give results differing by less than 1% on the average and less than 8% for specific photon energies.

For the distributed source problem, Spencer[44] has calculated the gamma-ray dose arriving within a small increment of solid angle at a detector in an infinite air medium above a plane source of infinite extent. The results of his calculations as a function of radiation angle of incidence and height of the detector above the source plane are shown in Fig. 5. Other calculations of the angular distribution of multiply scattered gamma radiation have been made by Berger.[45] French[46] has calculated the gamma-radiation environment three feet above a distributed source on a smooth ground surface by using Monte Carlo techniques.

In addition to air scatter, a problem also exists regarding the effect of the air-earth interface on any measurements that are made reasonably close to the surface of the earth. Berger[47] has calculated the expected energy dissipation because of the presence of the air-earth interface, for sources at the surface and at a height $\mu_0 \underline{h} = 0.5$, μ_0 being the narrow-beam attenuation coefficient in air of the source radiation. The energy of the primary radiation used by Berger in his calculations was 1.28 MeV. He concluded that (1) there is an increase of energy dissipation near the source, and a decrease far from the source, in such a manner that the total dissipation in a layer of given mass, parallel to the density-interface, is constant; (2) the increase is relatively small, not more than 20%; (3) with increasing source-detector distance, the decrease of energy dissipation of the interface compared to that in an infinite medium becomes more pronounced and tends toward 100%; and (4) the farther the detector is from the source, the greater the distance from the density-interface at which the perturbation is still noticeable.

Eisenhauer[48] discusses problems of the effects of ground roughness on the measured dose in air above a fallout source distributed on the ground. Effects of attenuation by the earth of radiation originating in crevices and depressions most commonly are approximated by a model that assumes that an infinitesimally thin planar source is buried beneath a given thickness of soil.[49] A variation of this model assumes the characteristics of the observed radiation to be equivalent to measurements made at some greater height ($\underline{h}$ + 3) feet above a smooth infinitesimally thin source of radiation.[47] The effect of the intervening earth is then treated as an equivalent amount of air. In at least one case[50] calculations were made in which the source material was assumed to be uniformly distributed through a layer of earth just below the air-earth interface.

Experiments Using Simulated Sources

Gamma radiation fields of deposited fallout have been simulated experimentally by spreading one or more gamma-ray emitting radionuclides over a flat area. An example is the work of Davis and Reinhardt[51] who simulated a fallout radiation field by means of plane rectangular arrays of ^{137}Cs and ^{60}Co sources. Individual sources in each array were 100 feet apart and the entire array covered an area 2000 feet on a side. The results were calibrated through use of point sources of ^{60}Co, ^{131}I, and ^{137}Cs. Davis and Reinhardt conclude that the use of a buildup factor for which the highest term is only a first power of $\mu\underline{h}$ is in relatively good agreement with experimental observations. This they conclude by showing that the buildup factors are approximately a linear function of height in the equation $\underline{B}\ (\mu\underline{h}) = 1 + \underline{a}\ (\mu\underline{h}) + \underline{b}\ (\mu\underline{h})^2 + \ldots$ for radiation from point sources. The magnitude of the coefficient $\underline{a}$ is larger for lower than for higher energy gamma radiations. Based on comparisons of their experimental results with calculations, Davis and Reinhardt conclude that an array of the type they used that is 2000 feet on a side is sufficiently large to simulate a uniform source of infinite area for measurements near the ground, but is inadequate for measurements of the ^{60}Co radiations at 500 feet altitude or higher.

In the spectral measurements by Davis and Reinhardt, a pronounced increase of low energy photons was observed in the measurements farther from the ground. These results give evidence of scattered radiation at those heights. More explicit information about the angular distribution of scattered radiation at a distance from a point source has been obtained from experimental measurements by Sakharov et al.,[52] whose measurements have indicated that, at distances from the source in excess of 150 meters, the angular distribution of scattered radiation at the detector is almost independent of the distance from the source. There appears to have been no attempt to correlate this work on the scattering of gamma rays with the results of Berger's[47] calculations. On the other hand, Clifford et al.[53] have experimentally measured gamma-radiation intensities at selected distances from a ^{137}Cs source located on a smooth clay surface and compared their results with Berger's work. They have determined the ratios of the intensities for this type of experimental arrangement to those obtained at comparable positions when the source is in a homogeneous air medium. Although the energy of the gamma radiation from ^{137}Cs is only 662 keV, Clifford et al. reasoned that both 662 keV and 1.28 MeV, the energy for which Berger[47] made his calculations, are in the energy region of Compton scatter for low and medium Z materials. Apparently their reasoning was correct for they found general agreement with the calculations by Berger.[47] Berger's type of calculation seems then to be applicable to other similar situations over a range of energies. Titus[54] has made similar measurements with a source at the interface between steel wool and steel, and reported good agreement with Berger's calculations. Titus' source was ^{60}Co. Subsequently, Clifford[55] found from use of distributed ^{137}Cs sources that ground roughness greatly reduced the dose received by a detector near ground level compared to the dose received from the same density of contamination on a smooth plane. Furthermore, he concluded that use in calculations of dose of an equivalent thickness of air rather than earth between source and detector causes an overestimate of the dose at low detector heights, at least for ^{137}Cs radiation.

Experiments Using Real Fallout Fields

Mather et al.,[56] Huddleston et al.,[57] and Frank[58] have measured the gamma radiation emitted by fallout that resulted from two near-surface bursts at the Nevada Test Site. All three groups used scintillation spectrometers, with NaI(Tl) detectors, to measure pulse height distributions. Mather et al. and Frank converted their results to photon energy spectra, and Huddleston et al. converted to units of incremental dose.

The detecting systems used by all three research groups were shielded in such a way that the incident radiation was directed into the detector through a collimator having a fixed aperture (solid angle of constant magnitude). If source material is uniformly distributed over a plane of infinite horizontal extent, the field of view through a collimator located above this plane is an amount of source material proportional to $(\cos \Theta)^{-1}$, where Θ is the angle in a vertical plane between the nadir and the axis of the collimator aperture. If the detector were able to record all source radiation in its field of view (no scattering or absorption), an infinite amount of radiation would enter as the collimator asymptotically approaches $\Theta = 90^\circ$ and no radiation would enter if $\Theta > 90^\circ$. Because ground and air molecules both

scatter and absorb gamma radiation, the air and earth intervening between source and detector attenuate the direct radiation, thus the maximum amount of radiation per unit solid angle that enters the collimator is finite, usually at an angle θ just slightly less than 90°. Some radiation, after being scattered by air molecules, also reaches the detector from angles for which $\theta > 90^\circ$.

A set of gamma-ray intensities as a function of angle of incidence is shown in Fig. 6* for four selected energy intervals of the nine-day

* Note that the angle θ both in Fig. 6 and in the text is measured from the nadir, whereas the angle θ used by both Mather *et al.* and by Frank is measured from the zenith.

old fallout that produced the radiation patterns of Fig. 1 (F through I). The measurements of Fig. 6 were made by Mather *et al.* at a point about 2.5 km downwind from ground zero in a radiation field of about 300 mR/hr. The surface texture was quite coarse, being primarily gravel. Plot *A* shows the directional characteristics of incident radiation measured in an energy interval encompassing the relatively intense 1.6 MeV photons emitted by the fission product, ^{140}La. The energy intervals encompassed by plots *B* and *C* are limited to much weaker source radiations than plot *A*, and the energy interval of plot *D* contains essentially no source radiation. The latter must then consist entirely of scattered radiation. Differences between scattered and direct gamma radiations are also quite apparent in the measured spectral characteristics of the radiation directionally incident from angles just below and just above the horizon. The distribution of photon energies incident from the lower hemisphere clearly shows energies up to about 2 MeV, with distinct peaks of monoenergetic gamma rays. However, only a relatively low energy continuous distribution is incident from the upper hemisphere. The maximum photon intensity in the scattered radiation from the upper hemisphere was found by Mather *et al.* to be about 75 keV. Frank, in somewhat similar experiments, found an intensity maximum in the photon spectrum at slightly more than 100 keV.

The effect of ground roughness has been determined in these experiments by measurements of the direct component of the radiation. Mather assumes this radiation to have an intensity I (in photons sec^{-1} cm^{-2} steradian^{-1}) given in the limited range of angles for which $0^\circ < \theta < 90^\circ$ by $I = S \left\{ \exp \left[-\alpha/\cos\theta \right] \right\} / 4\pi \cos\theta$, in which S is the mean source strength of the distributed fallout in units of photons sec^{-1} cm^{-2}. The parameter α is related to the average attenuation characteristics of the material between source and detector. The values of S for the gamma-ray intensity I were determined from the direct-radiation spectrum, and the values of α were determined from a comparison of the observed distribution of intensities of the direct radiation with that expected from an infinitesimally thin plane source in a vacuum (no absorption or scatter). In both cases the effect of ground roughness could be simulated by assuming a plane source covered by a layer of earth. In the area where Mather *et al.* made their measurements, the layer of earth amounted to a thickness of 0.45 g/cm^2 plus 106 cm of air, and in the area measured by Frank a thickness of 0.95 g/cm^2 plus 122 cm of air.

Huddleston *et al.* compared their dose vs. angle of incidence measurements with a calculation by Spencer[44] to determine the effects of ground roughness. They found angular distributions from measurements made three feet above the surface which, when compared with calculations made by Spencer, are comparable to the radiation expected in air about

40 feet above a planar infinitesimally thin source. Further, they found the distribution over a dry-lake bed to closely approximate Spencer's calculated distribution for an air-equivalent distance of 20 feet, and over a plowed field an air-equivalent distance of between 40 and 60 feet.

The equivalent air thickness reported by Huddleston et al. is somewhat greater (if converted to g/cm^2) than the equivalent earth thicknesses reported by Mather et al. and by Frank. The differences may have real significance or they may possibly depend on assumptions made in the calculations. The general conclusions derived from these results are that the use of an equivalent air attenuation to represent the soil attenuation produced by ground roughness effects appears to give results that are in reasonably good agreement with experimental observations.

Concluding Remarks

This discussion provides a brief summary of currently available information about ionizing radiations from fallout. A few references are attached to provide a basis for additional search of the literature. Such a large number of papers have been written on various aspects of the subject that a complete bibliography would be almost impossible for a meeting of this type. However, those references included should provide essentially all information that is needed.

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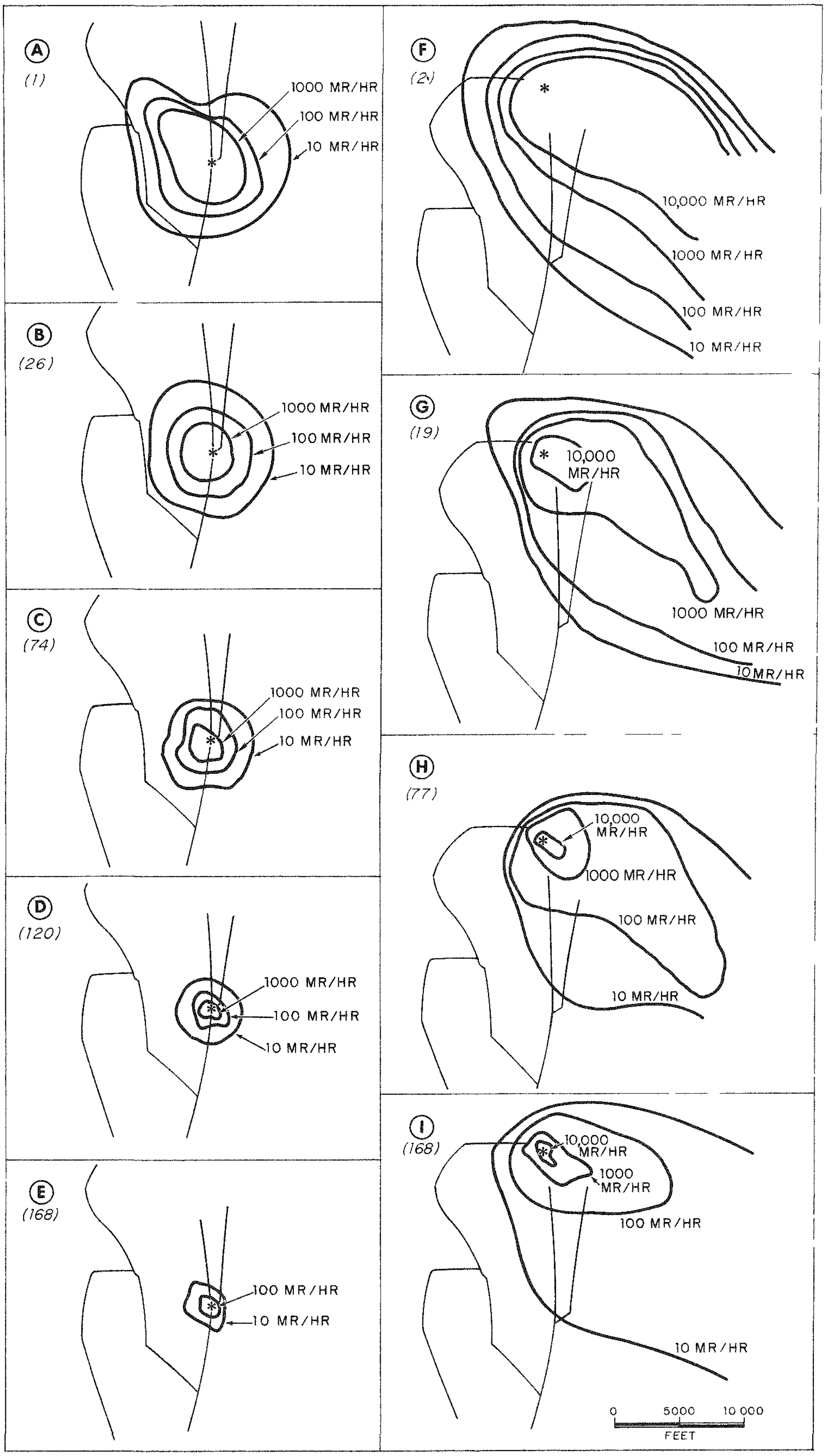
A
(1)
1000 MR/HR
100 MR/HR
10 MR/HR
B
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C
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D
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Fig. 1

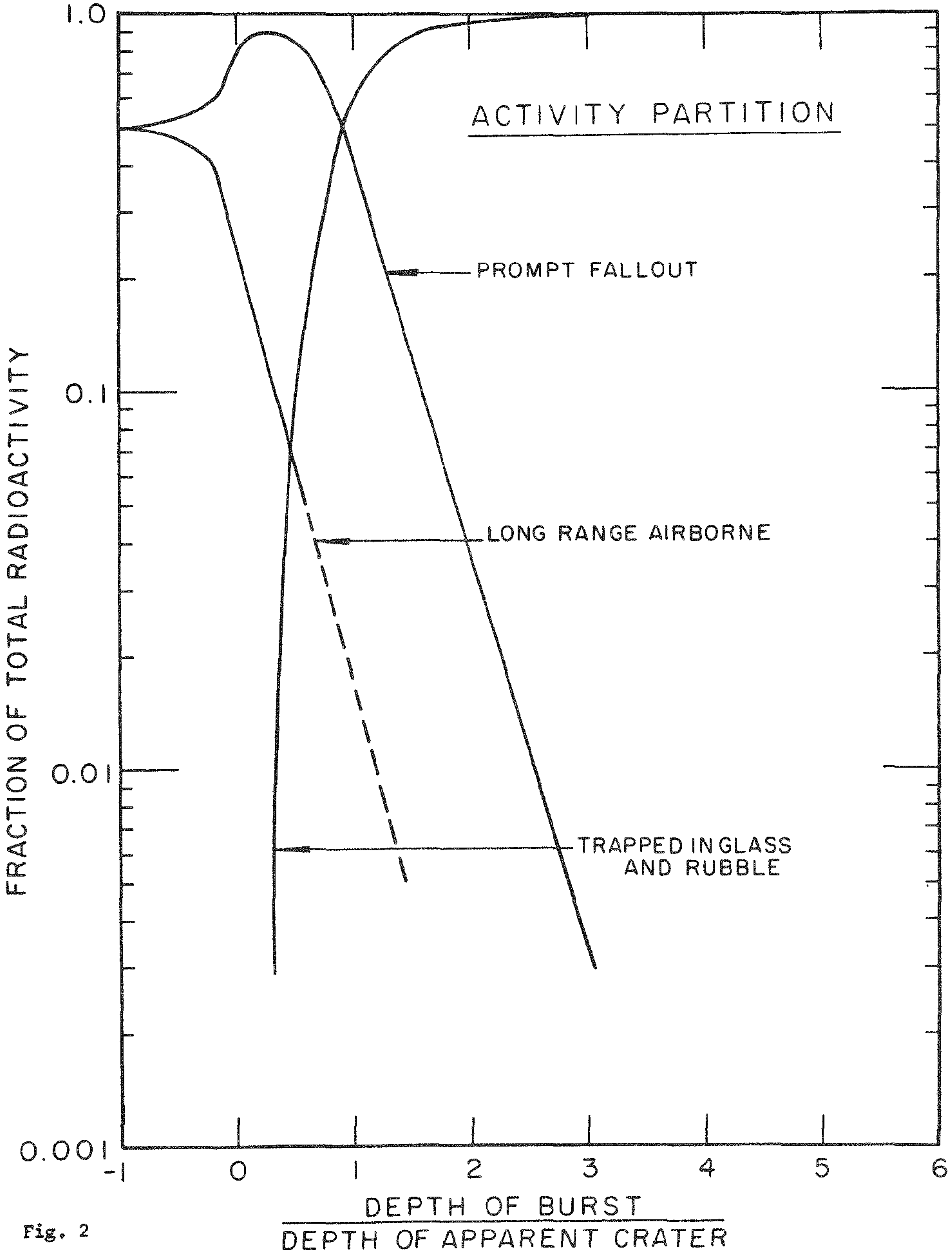
ACTIVITY PARTITION
PROMPT FALLOUT
LONG RANGE AIRBORNE
TRAPPED IN GLASS AND RUBBLE
FRACTION OF TOTAL RADIOACTIVITY
1.0
0.1
0.01
0.001
-1
0
1
2
3
4
5
6
DEPTH OF BURST
DEPTH OF APPARENT CRATER

Fig. 2

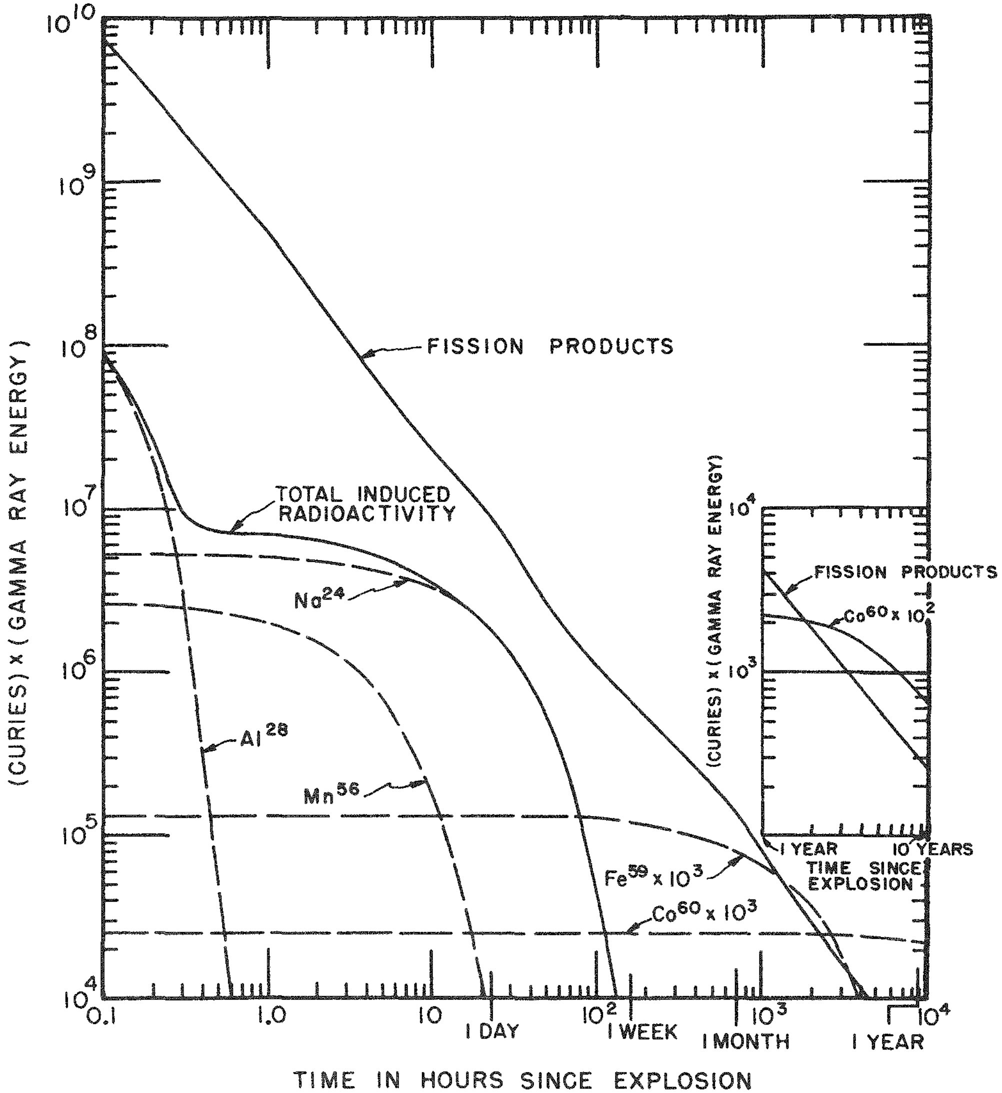
FISSION PRODUCTS
TOTAL INDUCED RADIOACTIVITY
Na24
Al 28
Mn56
Fe59 x 10^3
Co60 x 10^3
(CURIES) x (GAMMA RAY ENERGY)
10^10
10^9
10^8
10^7
10^6
10^5
10^4
0.1
1.0
10
1 DAY
10^2
1 WEEK
10^3
1 MONTH
10^4
1 YEAR
TIME IN HOURS SINCE EXPLOSION
FISSION PRODUCTS
Co60 x 10^2
10^4
10^3
1 YEAR
10 YEARS
TIME SINCE EXPLOSION

Fig. 3

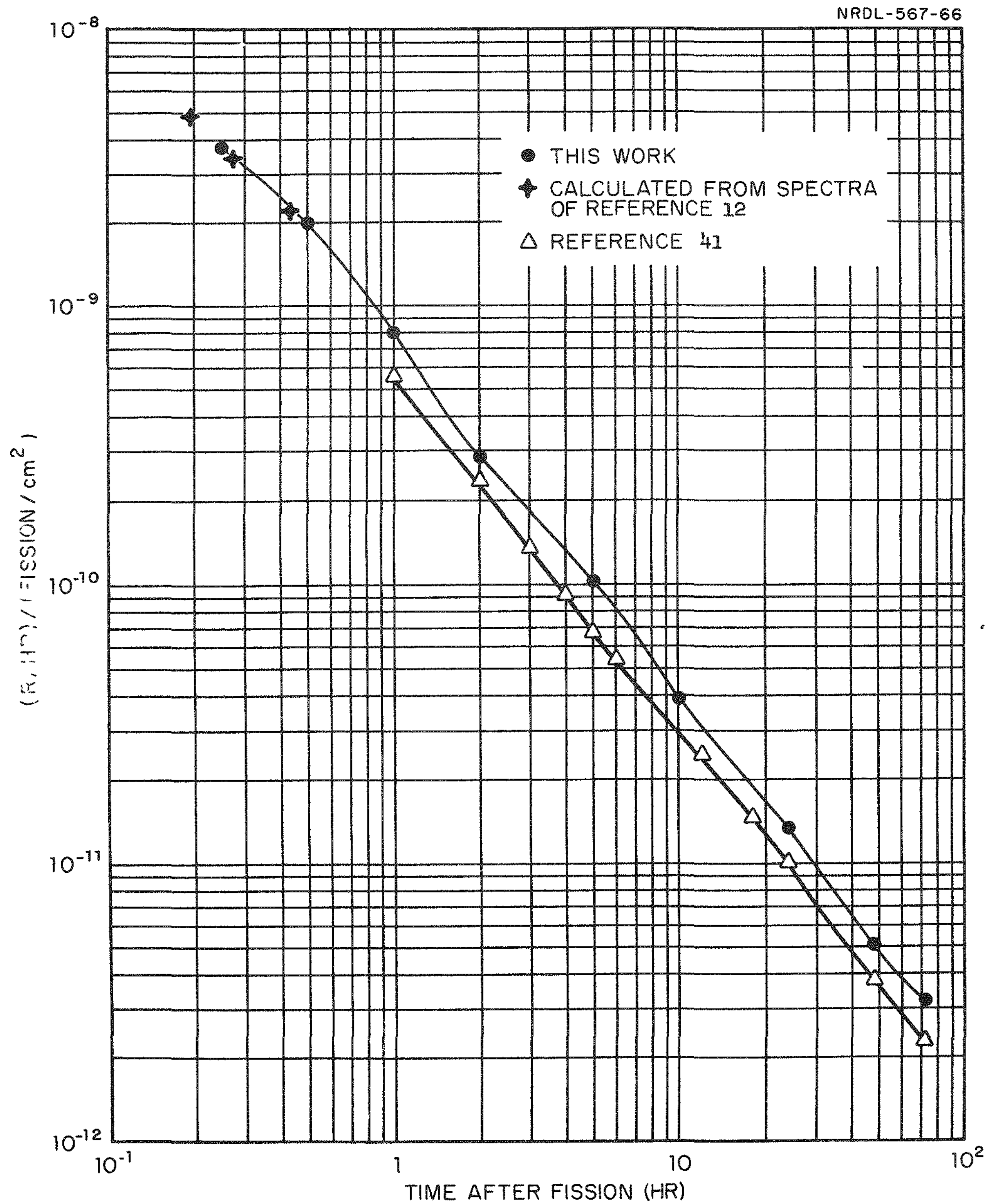
NRDL-567-66
THIS WORK
CALCULATED FROM SPECTRA OF REFERENCE 12
REFERENCE 41
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-1}
1
10
10^{2}
TIME AFTER FISSION (HR)

Fig. 4

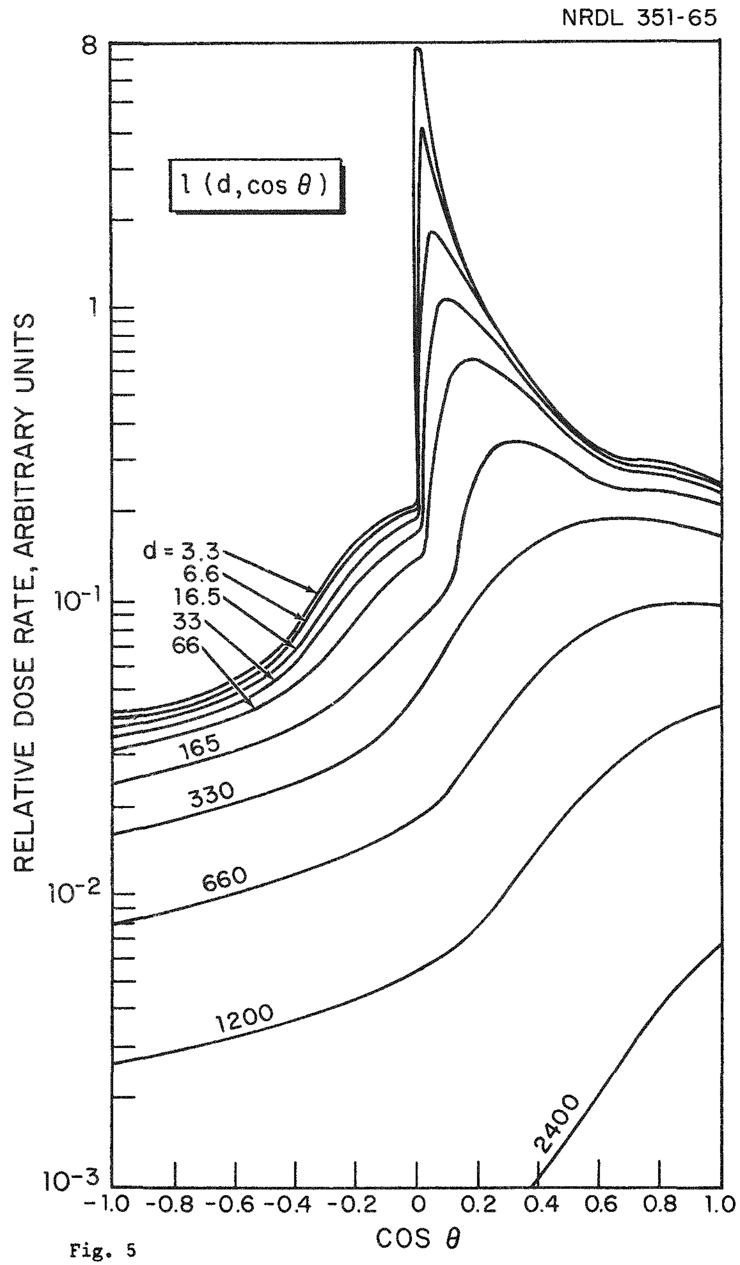
NRDL 351-65
I (d, cos θ)
RELATIVE DOSE RATE, ARBITRARY UNITS
8
1
10^{-1}
10^{-2}
10^{-3}
d = 3.3
6.6
16.5
33
66
165
330
660
1200
2400
-1.0 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1.0
COS θ

Fig. 5

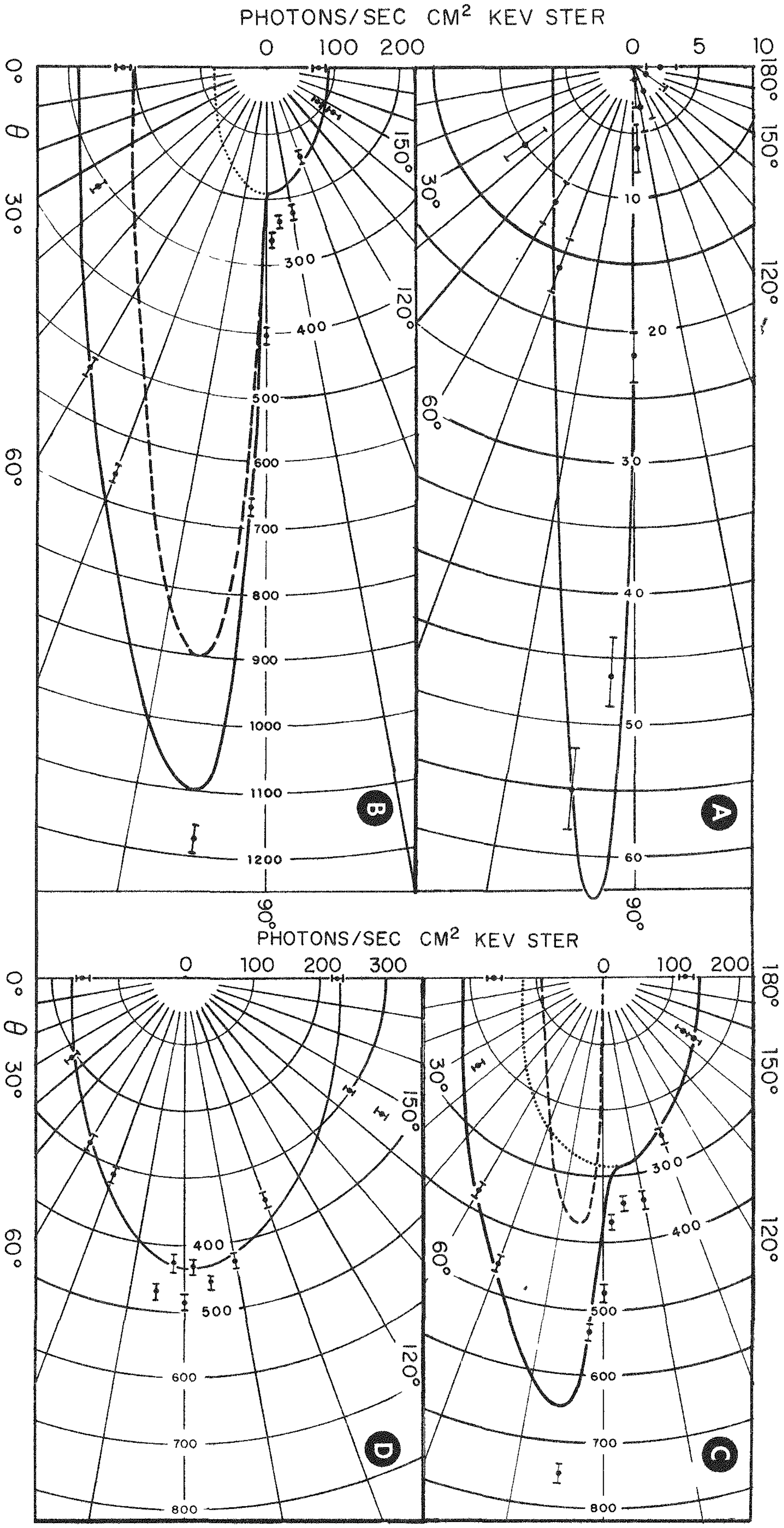
PHOTONS/SEC CM² KEV STER
0 100 200
0 5 10
0° θ 30° 60°
180° 150° 120°
30° 60° 90°
150° 120° 90°
10 20 30 40 50 60
300 400 500 600 700 800 900 1000 1100 1200
B
A
PHOTONS/SEC CM² KEV STER
0 100 200 300
0 100 200
0° θ 30° 60°
180° 150° 120°
400 500 600 700 800
300 400 500 600 700 800
D
C

Fig. 6

H

1.3

HALBLEITERMESSUNGEN VON FALLOUT

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Abstract:

Two γ-ray spectra of recent fission products, measured by a NaI well type crystal and a Ge(Li) drifted diode are compared. The high energy resolution of the small semiconductor compensates nearly its low detection efficiency and allows a much more reliable analysis of complex spectra within the monitoring of radioactivity. An example of an analysis is given.

Résumé:

Deux spectres-γ de produits de fission récents, mesurés par un crystal à puit de NaI et par une diode Ge(Li) sont comparés. La résolution excellente en énergie d'une petite diode compense à peu près sa faible éfficacité de détection et permet une analyse beaucoup plus précise des spectres complexes dans le cadre de la surveillance de la radioactivité. Un exemple d'une analyse est donné.

In einer neulichen Arbeit [1] wurden die Vorteile der Anwendung selbst kleiner, hochauflösender Ge(Li)-Dioden gegenüber NaI-Kristallen bei Ueberwachungsaufgaben am Beispiel von Falloutmessungen der chin. Atombombe vom 24.12.67 beschrieben. Die praktischen Erfahrungen, welche mit schwachen Proben (> 100 pCi/Isotop) gewonnen werden konnten, zeigen, dass Dioden wegen ihrer hohen Energieauflösung noch empfindlich genug sind, um als Detektoren von jungen Falloutproben eingesetzt zu werden. Wir konnten dazu die Messanordnung der Kernspektroskopiegruppe des Institutes benützen.

* Eidg. Kommission zur Ueberwachung der Radioaktivität.

Isotop	Halbwertszeit	Hauptlinie (keV)	Akt. am Explosionstag		Aus Nuklidakt. der Probe berechnete Anzahl Spaltungen von U-235
			Aus Analyse berechnet	Aktivitäten aus 10^4 Spaltungen von U-235 **	
			pCi	10^{-3} pCi	x 10^8
Np-239	56. h	106.14	34000		3.7 *
U -237	6.75 d	208.00	430		0.13 *
Mo- 99	67. h	--	2200	47.7	4.60
(Tc- 99	6.04 h	140.5			
Te-132	78. h	228.2	4000	28.4	14.1
(I -132)	2.3 h				
Xe-133	5.27 d	80.97	390	21.3	1.83
I -131	8.07 d	364.47	520	7.75	6.7
Nd-147	11.1 d	91.06	220	6.36	3.46
Ba-140	12.8 d	162.7	500	9.73	5.14
(La-140)	40.22 h	329.	560		
Ce-141	32.5 d	145.43	250	3.36	7.44
Ru-103	39.8 d	498.	140	2.77	5.05
Zr- 95	65.2 d	724.	220	2.22	10.0
(Nb- 95)	35. d	765.			
Ce-144	285. d	133.5	150	0.36	41.7
Cs-137	30. y	661.6	145	0.0134	1170.

Tabelle 1 : Analyse einer Probe der chinesischen Bombe vom 24.12.67

* Aus der Aktivität berechnete Anzahl Kerne.
** Werte von 3) korrigiert mit dem Verhältnis der Spaltausbeuten aus U-235 (Fissions-Neutronen) / U-238 (14 MeV-Neutronen).

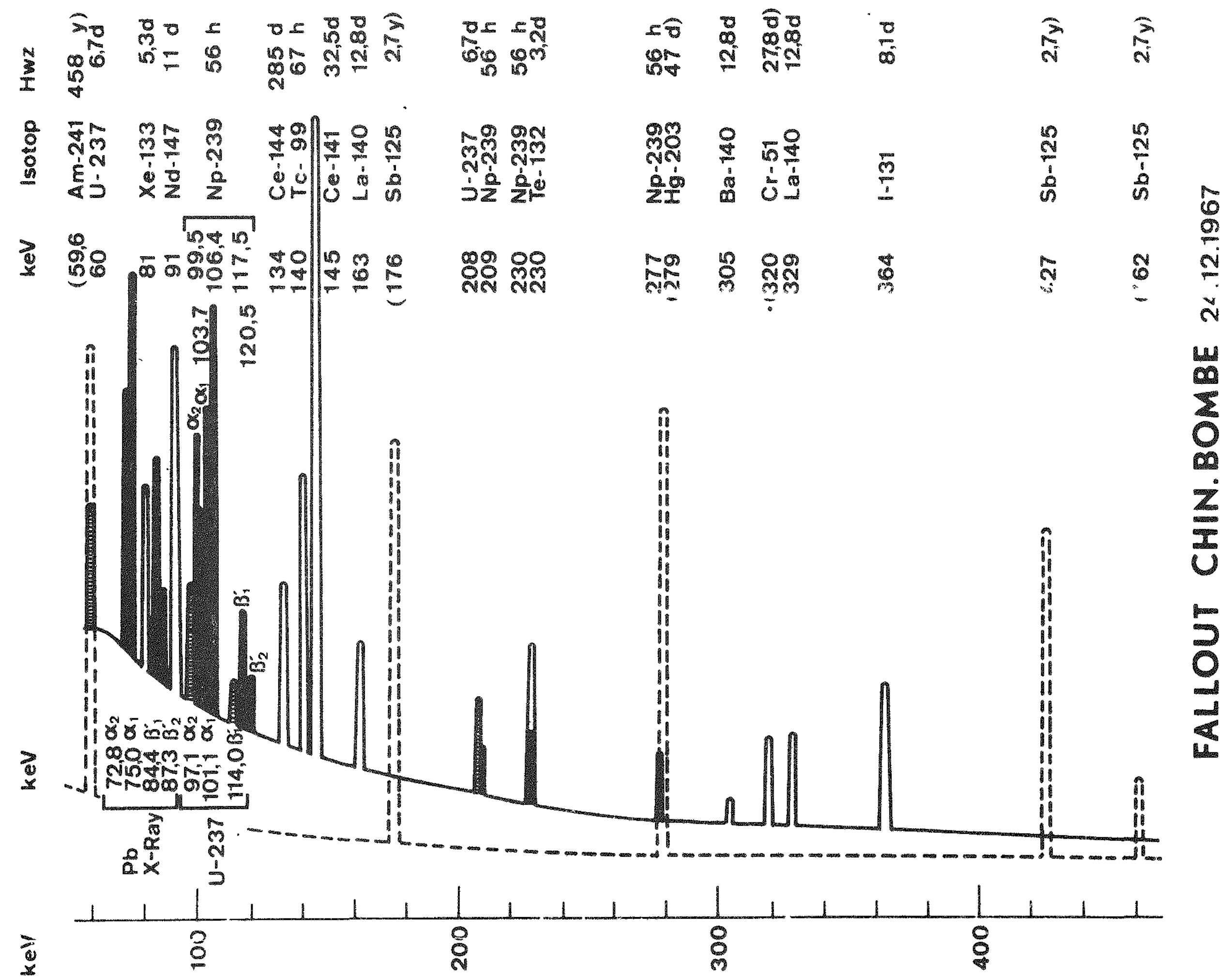
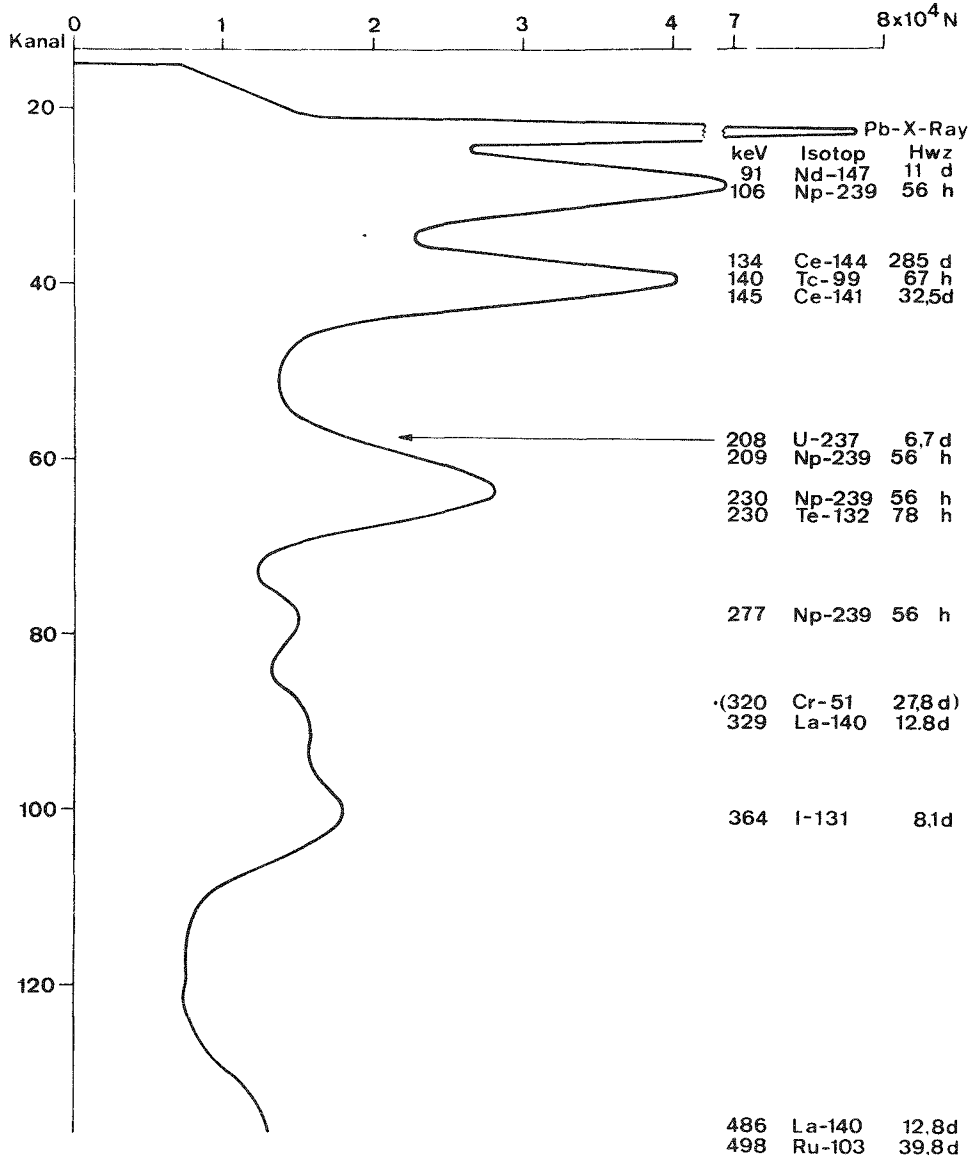
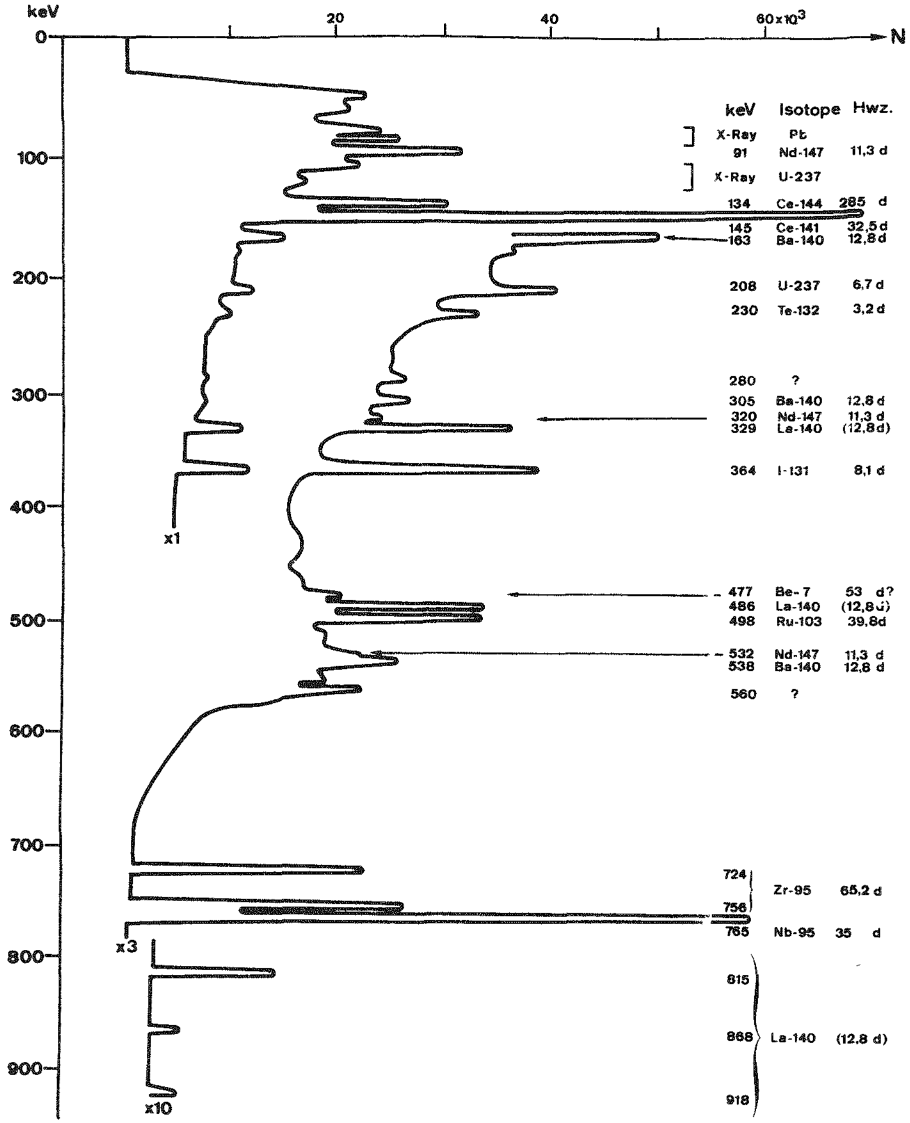


Fig.1



FALLOUT CHIN. BOMBE 24.12.1967
Bohrlochkristall 4,5x5", 8.1.68

Fig.3



FALLOUT CHIN. BOMBE 24.12.1967
Messung mit Ge(Li) Diode SB1 22.1.1968

Fig. 2

L

2.1

LOCAL FALLOUT HAZARD ASSESSMENT

By

Carl F. Miller

INTRODUCTION

In most previous and many current local fallout hazard assessment methods, model representations are essentially limited to fallout distribution and (gamma) exposure dose with a correction for biological recovery. These models, together with assumed biological response criteria and a set of shelter protection factors, are used to estimate casualties from fallout and to evaluate the cost-effectiveness of shelter systems in simple terms such as lives saved per dollar.

Information on fallout hazards has been available for some time to indicate a much more complex nature to the radiological hazards from fallout than depicted by this rather elementary system, and the hazard assessment methods are gradually being expanded and becoming more complex. Absorbed doses from beta radiation, in addition to gamma radiation doses, are being considered; and the scope of coverage on recipients has been increased to include radiological effects for a large variety of biological species. And, in the context of a hypothetical nuclear exchange, the measure of effectiveness of defensive systems are becoming increasingly sophisticated and tend to be associated with the standard of living or net income of survivors at some time after the exchange. The feedback of these developments, because of the demand for better and more abundant applicable data to carry out the more involved analyses, has attracted cooperative interest of many scientists in related fields of research; properly constructed models not only reveal how the research results are used and what further data are needed to resolve practical operational problems, but can be used as guidance in the design of experimental research.

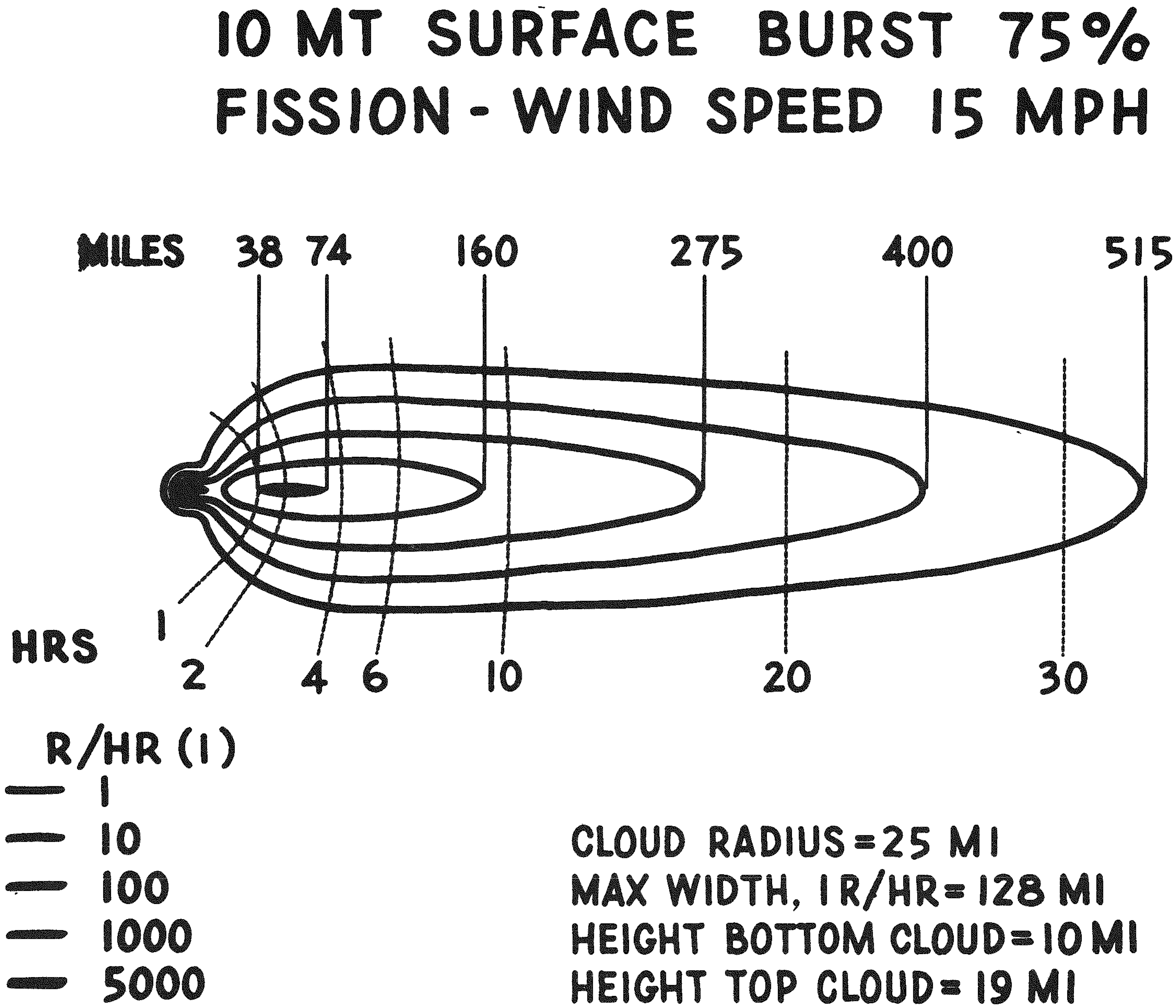


Figure 2. Idealized Fallout Pattern

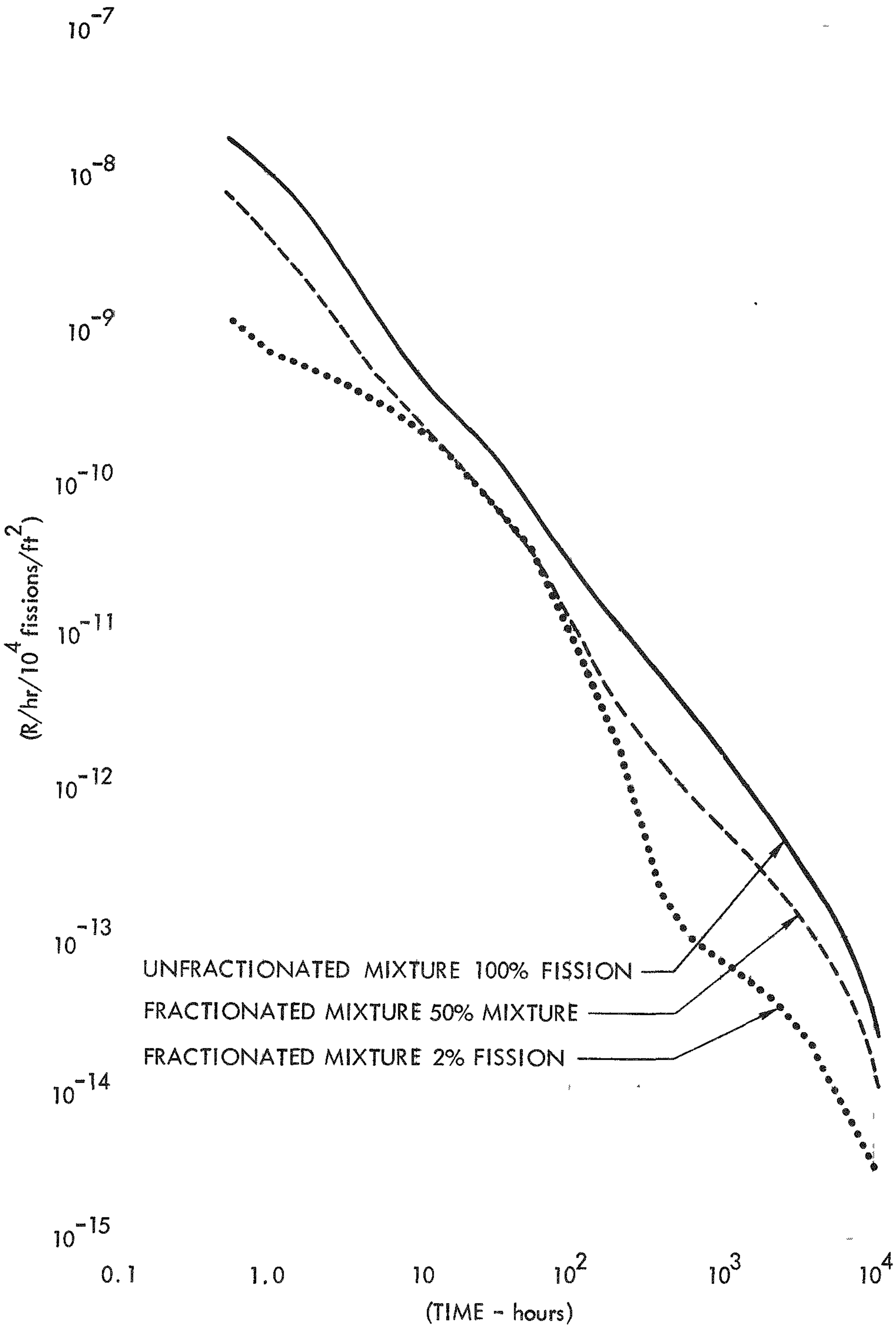


Figure 3. Computed Ionization Rate Curves for the Radionuclide Compositions in Fallout Particles of a Given Size Group From an Assumed 10-Mt-Yield Surface Detonation on Average Soil.

Actually a decay curve alone is not sufficient in estimating exposure doses from fallout radiation. Information on the time of arrival and increase in radiation or exposure rate during the period of fallout arrival is also needed. The variation of the exposure rate with time and the integrated exposure dose for the 2000 r/hr at 1 hr contour at a downwind distance of 45 to 50 miles (from Figure 2) are shown in Figure 4. Although the reference exposure rate or standard intensity (at one hour after detonation) is 2000 r/hr, the curve indicates that the maximum exposure rate is only slightly greater than 400 r/hr; the fallout arrival time is about 2 hours after detonation and the peak exposure rate occurs at about 3 hours after detonation.

The tabulated exposure doses show the characteristic rapid accumulation of dose at the early times; for the given location, about 30 percent of the 2.5 year dose is delivered in 10 hours (T = 12), about 64 percent is delivered up to 96 hours after detonation, and about 78 percent is delivered in the first two weeks after detonation. These percentages would increase for earlier arrival times at locations nearer to the point of detonation and would decrease for later arrival times at locations farther downwind.

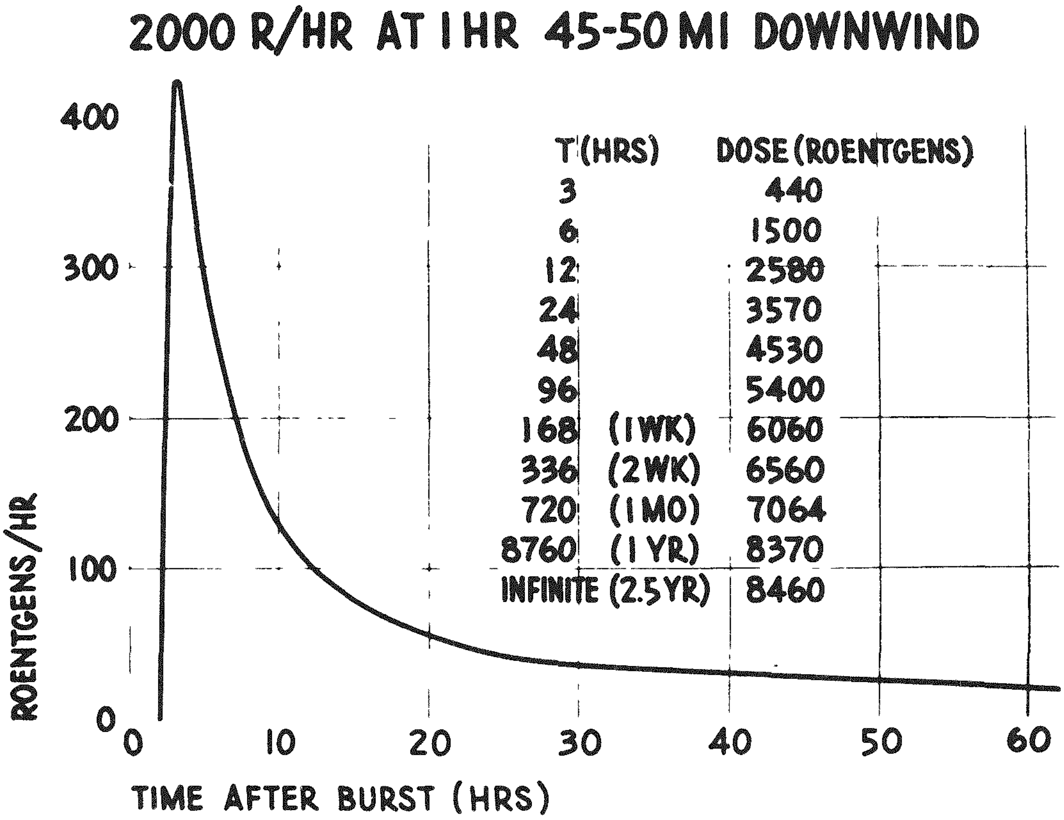


Figure 4. Variation of the Ionization Rate with Time and Associated Exposure Doses.

COMPUTATIONAL RESULTS

The detailed results of a series of computational results using the described assessment system are given in Reference 2; the general shape and coverage of the fallout contours from an assumed medium-level counterforce attack of almost 6000 megatons and a heavy mixed (counterforce plus countervalue) attack of almost 12,000 megatons on the United States are shown in Figures 5 and 6, respectively. The uniform east-west direction of the contours resulted from the use of averaged spring wind directions and speeds in the calculations. The particular maps of Figures 5 and 6 indicate possible effects of exposure dosage (beta dose effects were not considered) on forestland.

The calculations of the relative postattack agricultural production potential per capita for various crops and livestock are summarized in Table 1 for the two assumed attacks. The values in the table give an indication of the average crop or animal response to exposure dose relative to that for man (including location effects and time effects) for a June 1 attack. The probability of achieving the indicated potential was not estimated. Although the new data on foliar contamination were not used and contact beta doses were not estimated and the crop and animal fatalities (or loss of yield) were undoubtedly underestimated, their combined effect on Table 1 might not be very large because the largest contributing factor to crop loss was denial of access to harvest by the farmer (or death of the farmer in the shelter).

Estimates of the absorbed dose to a few body organs from ingestion of foods at the 50 and 90 percentile of the maximum contamination levels of available foods on a national basis are given in Table 2. Most of the absorbed doses are rather small when compared to the possible exposure doses. The only exception is the thyroid doses; converted to absorbed doses for infants, the 7,700 rem would become about 40,000 rem which would be sufficient to produce serious early effects.

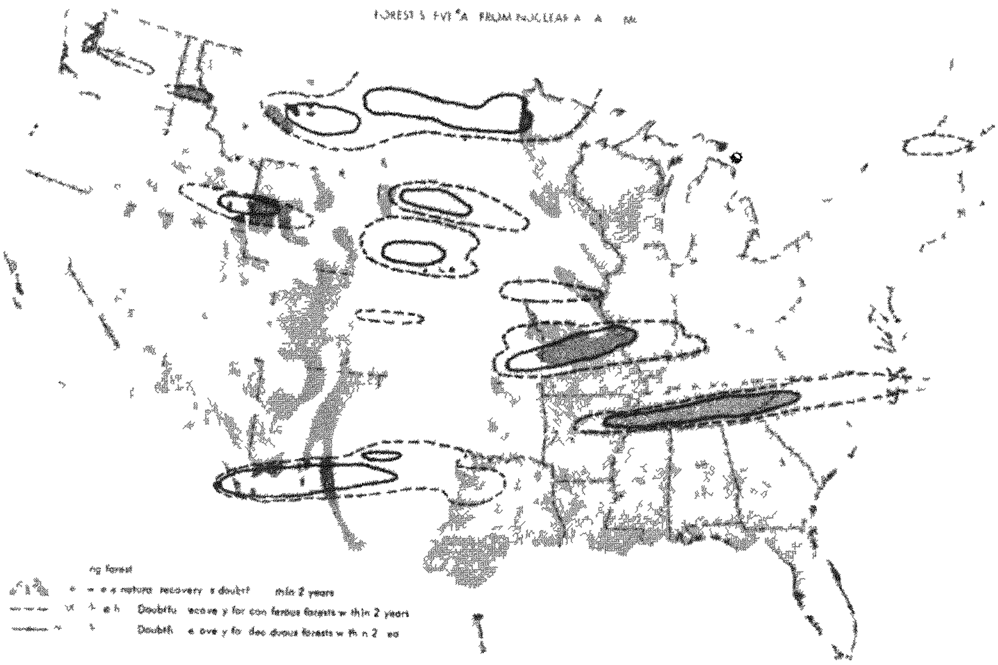


Figure 5. Forest Survival From Nuclear Attack MC

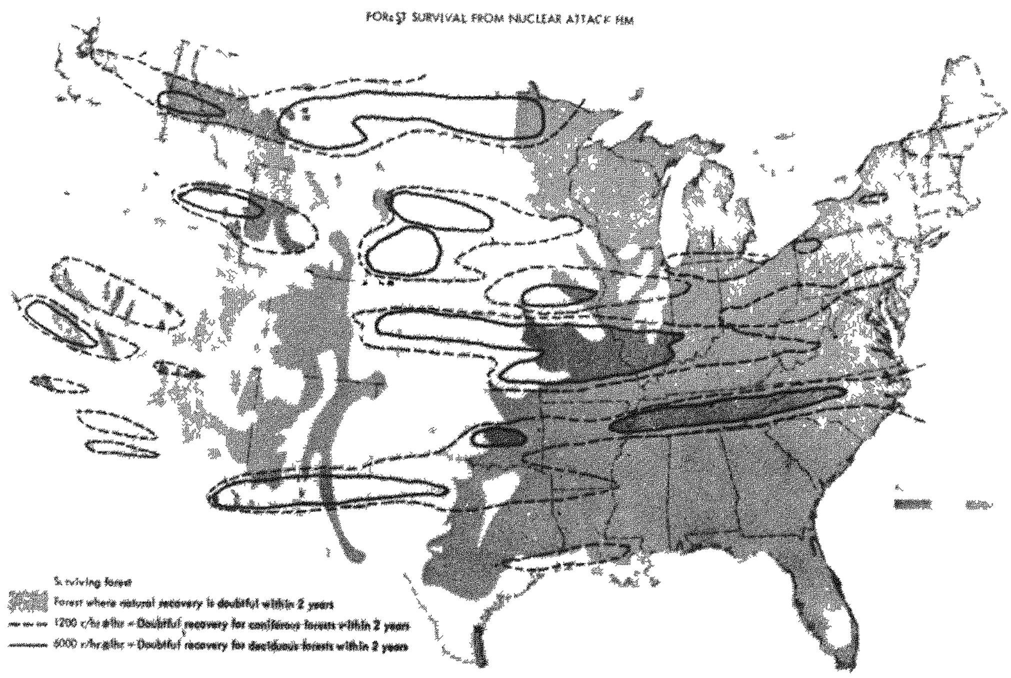


Figure 6. Forest Survival From Nuclear Attack HM

Table 1

POSTATTACK AGRICULTURAL PRODUCTION POTENTIAL PER CAPITA
(Values in Percent of Normal)

Crop or Livestock	HM Attack		MC Attack	
	Existing Shelter[a]	Good Shelter[b]	Existing Shelter	Good Shelter
Corn	92	92	92	97
Sorghum	140	95	93	100
Wheat	88	84	80	92
Oat	102	99	92	99
Barley	88	88	72	95
Bean, dry field	112	102	112	101
Soybean	130	98	101	97
Alfalfa	99	101	94	100
Hay	98	100	93	100
Potato	99	76	86	82
Green pea	146	104	114	101
Sugar beet	106	87	90	92
Tomato	131	85	109	98
Sweet corn	127	102	108	100
Snap bean	159	101	114	101
Cabbage	164	104	114	101
Onion	144	97	108	98
Carrot	171	104	105	101
Lettuce	171	102	114	101
Apple	117	93	106	97
Peach	112	84	111	99
Orange	126	88	114	101
Bull, steer, and calf	85	51	83	74
Milk cow	94	56	93	83
Swine	78	47	85	76
Sheep	106	66	91	81
Chicken	101	60	94	84

[a] Existing Shelter: PF = 10 for farmers; shelter survey data for urban population

[b] Good Shelter: PF = 1,000 for farmers; shelter survey data for urban population

Table 2

ABSORBED DOSE[a] TO ADULT HUMANS

FROM FOOD CONTAMINATED BY THE HM ATTACK: GOOD SHELTER

$t-t_o$ (days)	t_o[b] (days) 1	14	183	365	548
	At maximum concentration levels for 0.5 of available foods				
	Lower Large Intestine				
29	-	0.68	0.22	0.078	0.057
90	-	0.89	0.66	0.22	0.17
	Total Body				
29	-	0.35	0.22	0.007	0.006
90	-	0.76	1.8	0.055	0.042
	Bone				
29	-	0.74	0.29	0.039	0.031
90	-	2.0	2.5	0.30	0.25
	Thyroid				
29	-	440	-	-	-
90	-	540	-	-	-
	At maximum concentration levels for 0.9 of available foods				
	Lower Large Intestine				
29	6.3	13.7	10	0.88	0.66
90	11.7	21.0	30	2.6	2.0
	Total Body				
29	0.37	5.1	2.7	0.069	0.061
90	0.81	11.0	22.0	0.57	0.52
	Bone				
29	1.7	11	4.2	0.50	0.41
90	6.9	33	34.0	3.9	3.3
	Thyroid				
29	450	6,400	-	-	-
90	610	7,700	-	-	-

---

[a] In rem

[b] t_o is the time after attack when ingestion starts

The general conclusions of the study were that agricultural land would not need to be decontaminated because of contamination by Sr-90 and Cs-137; that up to about 90 percent of the harvestable crops would be edible; that more than 10 percent (beta-contact dose effects being unknown) of the planted crop land and more than 10 percent of the forestland could be seriously effected or destroyed by radiation; and that, except for limited areas, the delayed reentry because of exposure dose limitation to the farmer in agricultural areas should not be so long as to give rise to possible long-term ecological problems.

In a small fraction of the total area of the United States, the assumed two attacks are estimated to produce gamma radiation levels sufficiently high to produce fatal doses to all higher forms of life in exposed conditions and to denude the landscape of vegetation. In all instances, the severest effects are due to relatively short-term hazards and the alleviation of both short-term effects and consequent longer-term effects centers on the availability of adequate shelter for the population and a local capability coping with recovery problems in the early postattack period.

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BETA RADIATION HAZARDS AND BETA-GAMMA RELATIONSHIPS ASSOCIATED WITH LOCAL FALLOUT

2.2

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INTRODUCTION

In recent years an increasing amount of attention has been given to external beta-contact hazards associated with local fallout from nuclear detonations.

This paper presents a discussion of the beta hazards and beta-gamma relationships essential to the determination of whether a requirement exists for radiological protection from beta radiation associated with local fallout in a nuclear mass disaster.

THE BETA HAZARDS

Skin surfaces exposed to mixed fission products will be irradiated by both beta and gamma radiation. Since the beta radiation is much less penetrating than the gamma, the skin dose from the former will be very much greater relative to the depth dose. However, a substantial fraction of the energy is deposited in the dead cornified layer of the epidermal tissues which averages 70-100 microns in thickness. The dose at the basal epidermis is of major interest in the evaluation of the significance of a skin exposure.

As an example of the importance of this basal layer, Table 1 is reproduced from reference 1. The authors indicated that the dose required for microscopically recognizable transepidermal injury at the base of the porcine epidermal layer (estimated at 90 microns) is approximately constant at 1400 ± 300 rep even though the accompanying surface doses may vary widely, (the rep, an obsolete unit, may be taken as essentially equal to the rad).

Skin exposures to miniature white swine for 1 and 4 hour periods have been made* using simulated reactor debris (1-mm diameter) enhanced with Sr^{89} + (Sr^{90}-Y^{90}), delivering a dose rate of about 4000

* Personal communication, J.R. McKenny to R.E. Thompson, Battelle Northwest, June 7, 1965.

rads per hour at 50 mg/cm^2 tissue depth. Following the one-hour exposure (4000 rads) a slight, very localized erythema developed between 10 and 15 days. After the four-hour exposure (16,000 rads) a slight erythema could be seen immediately; after 15 to 20 days, a more severe erythema developed, followed by necrosis of an area about 3-mm in diameter and the appearance of a crusted ulcer by 30 days.

Four cases of beta-ray burns of the hands, which occurred during an atomic bomb test at Eniwetok, have been reported by Knowlton et.al.[2] Two of the men received beta ray doses of 5,000 - 10,000 rads, another received 8,000 - 16,000 rads, and the fourth received 3,000 - 4,500 rads. For all but the smallest dose, skin damage was so extensive that grafts were required. There was loss of mobility of some of the fingers. In one case serious ulcers persisted for periods greater than 100 days after the exposure. The effects of the smallest dose were less pronounced; however, the damage persisted for a period greater than 50 days.

An accident resulting in superficial skin burns to 6 people from scattered cathode rays is described by Robbins et. al.[3] The cathode-ray energies involved were considerably greater than the average energy of P^{32}. The resulting burns covered larger areas of skin. Actual doses received could not be determined, but careful dosimetry following the accident placed the maximum exposures somewhere between 1500 and 2500 rads. The results follow the pattern of other irradiations cited. The lesions appeared in three phases, the last one becoming manifest approximately four weeks after exposure. The burns were analogous to, but different from, thermal burns and roentgen-ray reactions in that only superficial layers of tissue were involved. In one patient, a skin graft was necessary on the 190th day after

exposure due to a 4-mm area on the index finger that broke down and began to granulate. At ten months after exposure the hand had healed (93 days after grafting).

TABLE 1

Amount of Transepidermal Radiation Required for the Production of Recognizable Transepidermal Injury (Porcine Skin) From Ref. (1)

Isotope	Maximum Beta Energy (Mev)	Surface Dose Required (rep)	Estimated Dose at 0.09-mm Depth (rep)
S-35	0.17	20,000	1200
Co-60	0.31	4,000	1600
Cs-137	0.55	2,000	1700
Y-91	1.53	1,500	1200
Sr-90	0.61	1,500	1400
Y-90	2.20		

A recent report by Conard [4] on the ten year study of the Marshallese people exposed to Fallout Radiation indicates that during the past several years an increased number of pigmented nevus-like lesions have been noted in previously irradiated areas of the skin but these have appeared to be quite benign. Neither chronic radiation dermatitis nor evidence of cancer of the skin has been noted. It should be pointed out, however, that the latent period for skin cancer from irradiation in humans is probably as long as 15-20 years.

Alpen [5] has summarized the expected effects on skin of beta radiation exposure over relatively large areas of skin. His summary is reproduced in Tables 2 and 3 of this report. The sources of the results presented in these tables include the accurate surface exposures made by Low-Beer[6] using P^{32} plaques directly in contact with human skin. The doses varied between 150 and 17,000 rep. Dry desquamation (peeling of the outer area, leaving a dry incompletely healed surface)

occurred at doses of 7200 rep. Wet desquamation (loss of outer layer, leaving a wet unhealed surface) occurred at 17,500 rep.

TABLE 2

Summary of Biological Effects of Beta Radiation on the Skin*

Effects of beta radiation are of four types:

a. Immediate - appearing from 0 to 48 hours after exposure.

1. Erythema (reddening of the skin, as in severe sunburn) and itching. Estimated dose required (EDR): 600-1000 rads. If 600 rads, will probably appear within 48 hours; if 1000 rads, will probably appear within 24 hours.

2. Vesication (formation of blisters). EDR: between 30,000 and 100,000 rads.

b. Delayed - appearing from one to five weeks after irradiation.

1. Second wave erythema. EDR: 600-1000 rads.

2. Vesication and Desquamation (loss of skin). EDR:2500 rads.

3. Epilation (loss of hair). EDR: 300-700 rads. Not significant generally.

c. Persistent Changes

1. Radiation Dermatitis. Persistent ulceration in which skin repeatedly breaks down. Requires replacement of skin. EDR: more than 6000-10,000 rads.**

2. Vascular Changes. Visible spiderwebbing of surface veins. May contribute to dermatitis. If not, not operationally important. EDR: 500 rads, to the blood vessels.

3. Atrophic Changes. Skin becomes very thin and easily damaged. No estimate as to EDR.

d. Long-term - appearing after one year.

1. Tumor induction. EDR: 1000-2000 rads. A statistically significant increase in tumors has occurred in irradiated animals. Not predictable on an individual basis. A genetic effect at the cellular level.

2. Less severe radiation dermatitis. No estimate as to EDR.

3. Cataract formation. EDR: 2000 rads to lens.

*Taken from reference 5, except for footnotes...

**In reference 5 this is given as "600-1000 rads," it is assumed that the stated values are due to a typographical error; they are therefore corrected as above.

TABLE 3

Acute Effects of Ionizing Radiation on Skin *

Estimated Dose Required (EDR) in 1 Week	
0-600 rad	No acute effects
600-2000 rad	Moderate early erythema
2000-4000 rad	Early erythema under 24 hours Skin breakdown** in 2 weeks
4000-10,000 rad	Severe erythema in 24 hours Severe skin breakdown** in 1-2 weeks
10,000-30,000 rad	Severe erythema in 4 hours Severe skin breakdown** in 1-2 weeks
30,000-100,000 rad	Immediate skin blistering (less than 1 day)

*Taken from reference 5, except for footnotes.

**When the dose is due to beta radiation, the skin epithelium may suffer severe breakdown without destruction of the dermis (true skin). More penetrating radiation destroys the true skin and causes ulceration.

The effects of very high doses to small areas of the skin are not known, since there is very little information on this type of exposure. An experiment by Passoneau [7] that may bear on this was done on rat skin and is presented in Table 4 which appeared in the National Academy of Sciences inhalation report. [8] In this experiment, rats were exposed for periods of two days to 1500 μc of Sr^{90}- Y^{90} which was either spread uniformly over an area or divided equally into 10, 20, or 50 small beads. Malignant and benign tumors were formed in all cases, but fewer tumors were formed by exposure to the point sources than to the same activity uniformly distributed. The number of tumors produced per bead was largest for the beads with the most activity, but the number of tumors per microcurie was less for the stronger beads than for the weaker.

In addition to the beta-radiation experiment described above, a series of experiments has been done by Joles [9]. The results indicated that for X rays, the degree of skin reaction is dependent upon the product of the exposure in roentgens and the area exposed, rather than on exposure alone. Following is an example of observed effects:

Two separate areas of human skin 0.5 cm^2 and 3.0 cm^2 were irradiated, with single exposures of 2500 R. On the third day a moist discharge was observed in the larger area. In six days the area began to crust. An ulcer formed on the 10th day and persisted for 28 days. Complete recovery had not occurred 150 days after irradiation. In the smaller area, a moist discharge was observed on the 14th day and lasted for six days. Recovery began on the 26th day and was complete in 60 days.

TABLE 4

Tumor Production in Rat Skin Upon Exposure to Flat Plate and Point Sources (From Reference 7, 8)

Source	Activity	Number of Animals	Number of Tumors (a)	Tumors per μc	Relative Efficiency*
Flat Plate 1000 μc	28.6 μc/cm^2	71	89	4.94×10^{-4}	1.59
Flat Plate 1500 μc	42.9 μc/cm^2	73	(b)	(b)	(b)
50 beads	30 μc/bead	58	27	3.10×10^{-4}	1.00
20 beads	75 μc/bead	77	24	2.08×10^{-4}	.671
10 beads	150 μc/bead	74	16	1.44×10^{-4}	.464

(a) Obtained by private communication from A. M. Brues, January, 1953.

(b) These data are not available.

*Number of tumors produced per microcurie relative to the number produced per microcurie for the 50-bead experiment.

Based therefore on the reports of Passoneau (7, 8) and Joles (9), it seems that the effect from an individual small particle should be less than that expected from a distributed source delivering the same dose at the base of the epidermis.

CONTACT BETA DOSES ASSOCIATED WITH GAMMA RADIATION MEASUREMENTS

Estimations of the contact beta doses associated with gamma-radiation measurements of nuclear weapon fallout were reported a number of years ago[10]. A condensation of the material of those reports is presented here. The calculations were made for early fallout from nominal-yield weapons based both on experimentally determined beta-to-gamma ratios and on a combination of experimental measurements of beta dose rates to the skin of animals from P^{32} plaques and the calculated gamma exposure rates expected from contaminated smooth circular planes of various sizes.[10] Table 5 shows the expected gamma-radiation measurement at six inches from plane circular thin sources with radii ranging from 2-cm to 33.4-cm for a specific activity of 1 $\mu c/cm^2$ and an average energy of 1 Mev. The radii of 18.2-cm and 33.4-cm are the radii of circles of equivalent areas approximately representing the side and the front respectively of man.

TABLE 5

Calculated Gamma Exposure Rates at 6 Inches Above Center of Plane Circular Sources of Various Radii for 1 $\mu c/cm^2$ and 1 MeV Gamma Photon Energy (from Reference 10)

Radius (cm)	Exposure Rate milliroentgens/hr
2	0.3
4	1.1
6	2.9
10	5.7
18.2	15.0
33.4	29.0

An equation for the estimation of gamma exposure rates in R/hr was presented previously[10] in the form.

$$I_\gamma = \mu_E \, kf(\mu) \, AE \qquad (1)$$

where

μ_E = Klein-Nishina energy absorption coefficient ($3.5 \times 10^{-5} cm^{-1}$ used here)

k = a constant (1.44×10^{-5} R/MeV times 1.332×10^{8} dis/hr per μCi)

$f(\mu)$ depends upon the total linear absorption coefficient

A = The specific activity ($\mu Ci/cm^2$)

E = the γ-energy (MeV/photon)

The gamma exposure rates at a survey distance of 6 inches from circular areas of various sizes contaminated with radioactive fallout of unit specific activity and emitting gamma radiation of 1 MeV energy were calculated by using the values of K shown in Table 6.

K shown in the table is equal to $\mu_E kf(\mu)$.

TABLE 6

Values of K for Contaminated Circular Areas of Various Sizes
(from Reference 10)

Radius (cm)	K X 10^3
2	0.3
4	1.1
6	2.9
10	5.7
18.2	15
33.4	29

Table 7 shows the beta-gamma relationships expected for these same radii on the basis of the relationship I_γ=KAE (See Table 6 for values of K when E and A are equal to unity) and the relationship reported previously[10]: I_β=5.5 A, where I_β is the beta dose rate in rads/hr and A is the activity per unit area in microcuries per square centimeter for P^{32} beta energy (similar to the average beta energy of fresh fission products).

The expected beta dose rate at contact in a large field contaminated by fallout was calculated [10] to be 40 times the gamma exposure-rate reading taken at 3 feet. For example if the gamma reading at 3 feet is 100 R/hr, the expected beta dose rate at contact will be 4,000 rads/hr. This is true for a beta-particle to gamma-photon ratio of 1. This ratio is approximately equal to unity for times after a nuclear burst of a few hours to 3 or 4 months. At early

times (a few minutes to an hour) the ratio may be as high as 2, in which case the beta dose rate will be 80 times the gamma exposure rate.

The beta doses associated with local fallout contamination of terrain and clothing have also been estimated by Pretre[11] who compared the beta and gamma doses to people exposed to terrain and clothing contaminated with fallout. His calculations were essentially in agreement with those reported in reference 10.

TABLE 7

Beta Dose Rates Corresponding to Various Gamma Exposure-Rate Measurements at 6 Inches Above Center of Plane Circular Sources* of Various Radii

Radium (cm)	Beta Dose Rates (Rads/hr) .2 R/hr	1 R/hr	10 R/hr
2	3.6×10^3	1.8×10^4	1.8×10^5
4	1×10^3	5×10^3	5×10^4
6	3.6×10^2	1.8×10^3	1.8×10^4
10	1.8×10^2	9×10^2	9×10^3
18.2	7.4×10^1	3.7×10^2	3.7×10^3
33.4	3.6×10^1	1.8×10^2	1.8×10^3

*Average gamma photon energy of 1 MeV; average beta energy that of P^{32} (equivalent to that of early fission products).

In a recent report[12] the beta doses due to fallout radiation for nuclear weapon yields of 1, 10 and 100 MT have been computed for a tissue depth of 0.003 cm at various air gaps separating the tissue surface from the contaminated surface. Typical results of these computations are shown in Tables 8 and 9 listing the 5-day and 45-day beta doses at contact and for air gaps of 10 and 100 cm for a point on each of the standard intensity contours 1, 10, 50, 100, 200, 500, 1000 and 2000 R/hr at 1 hr. The point selected for each contour was at half the distance from the burst point to the maximum downwind distance of the contour.

The associated gamma doses estimated from Effects of Nuclear Weapons[13] would be about 1/60 to 1/100 of the contact beta doses listed in the tables.

TABLE 8

Approximate 5-day Beta Doses* (from reference 12)

Exposure Rate Contour (r/hr at 1 hr)	1	10	50	100	200	500	1000	2000
1 MT weapon burst								
Downwind mid-distance on contour (miles)	119	86	62	52	42	39	19	--
Contact beta dose (rads)	9.40+1**	1.16+3	7.43+3	1.67+4	3.87+4	1.00+5	2.87+5	--
Beta bath dose - 10 cm air gap (rads)	4.00+1	4.82+2	2.76+3	6.23+3	1.29+4	3.27+4	8.32+4	--
Beta bath dose - 100 cm air gap (rads)	8.85+0	1.05+2	6.33+2	1.46+3	3.04+3	7.84+3	2.12+4	--
10 MT weapon burst								
Downwind mid-distance on contour (miles)	247	187	145	128	105	86	69	51
Contact beta dose (rads)	5.50+1	7.70+2	4.01+3	8.68+3	2.06+4	5.90+4	1.39+5	3.41+5
Beta bath dose - 10 cm air gap (rads)	2.70+1	3.25+2	1.89+3	4.00+3	8.93+3	2.41+4	5.34+4	1.20+5
Beta bath dose - 100 cm air gap (rads)	7.00+0	6.30+1	3.92+2	8.33+2	1.92+3	5.33+3	1.22+4	2.81+4
100 MT weapon burst								
Downwind mid-distance on contour (miles)	509	401	326	293	261	218	186	143
Contact beta dose (rads)	4.00+1	3.95+2	2.36+3	5.02+3	1.16+4	3.08+4	6.72+4	1.62+5
Beta bath dose - 10 cm air gap (rads)	1.50+1	1.88+2	1.11+3	2.37+3	5.15+3	1.48+4	3.25+5	7.53+4
Beta bath dose - 100 cm air gap (rads)	2.40+0	3.20+1	2.06+2	4.39+2	9.71+2	2.88+3	6.50+3	1.57+4

* 15 MPH wind and 50% fission yield with no terrain-roughness and instrument-response factors.

** 9.40+1 means 9.40 x 10^1; 1.16+3 means 1.16 x 10^3; etc.

TABLE 9

Approximate 45-day Beta Doses* (from reference 12)

Exposure Rate Contour (r/hr at 1 hr)	1	10	50	100	200	500	1000	2000
1 MT weapon burst								
Downwind mid-distance on contour (miles)	119	86	62	52	42	39	19	--
Contact beta dose (rads)	2.40+2	1.64+3	9.92+3	2.17+4	4.81+4	1.25+5	3.36+5	--
Beta bath dose - 10 cm air gap (rads)	5.90+1	6.83+2	3.77+3	8.21+3	1.69+4	4.29+4	1.04+5	--
Beta bath dose - 100 cm air gap (rads)	1.13+1	1.31+2	7.57+2	1.73+3	3.56+3	9.15+3	2.38+4	--
10 Mt weapon burst								
Downwind mid-distance on contour (miles)	247	187	145	128	105	86	69	51
Contact beta dose (rads)	1.04+2	1.16+3	6.50+3	1.36+4	3.00+4	8.38+4	1.88+5	4.36+5
Beta bath dose - 10 cm air gap (rads)	4.70+1	5.26+2	2.89+3	5.98+3	1.29+4	3.43+4	7.43+4	1.60+5
Beta bath dose - 100 cm air gap (rads)	9.70+0	9.00+1	5.16+2	1.10+3	2.44+3	6.65+3	1.48+4	3.33+4
100 Mt weapon burst								
Downwind mid-distance on contour (miles)	509	401	326	293	261	218	186	143
Contact beta dose (rads)	8.90+1	8.79+2	4.85+3	9.95+3	2.10+4	5.57+4	1.17+5	2.56+5
Beta bath dose - 10 cm air gap (rads)	3.50+1	3.89+2	2.12+3	4.35+3	9.15+3	2.50+4	5.33+4	1.15+5
Beta bath dose - 100 cm air gap (rads)	5.00+0	5.90+1	3.30+2	7.05+2	1.49+3	4.20+3	9.16+3	2.10+4

* 15 MPH wind and 50% fission yield with no terrain-roughness and instrument-response factors.

The tables and discussion have presented background material for estimation of beta dose rate hazards from gamma exposure-rate readings under ideal situations. The techniques for small areas imply that the gamma background is zero or low enough not to interfere with the interpretations.

The implications of the relationships and hazards presented above must be considered in the determination of the requirements for decontamination and for radiological protection from beta radiation associated with local fallout in nuclear mass disasters.

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THE CLINICAL CONSEQUENCES OF PROTRACTED EXPOSURE TO FALLOUT 2.3

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Fortunately for all, data concerning the effects of protracted exposure to fallout have not been made available since the publication of Report No.29 through the occurrence of catastrophes. In this presentation I shall attempt to assess those bits of human data that have accumulated during the past ten years in an attempt to determine if the basic clinical premises used in the planning for Report No. 29 and their relation to radiation dose were far astray.

The large mass of data derived from animal studies simulating in some respects total doses and dose rates to be expected in the cases of fallout under emergency conditions are being discussed by my colleagues during this session. With the exception of one study to be discussed later the data concerning human effects do not resemble the actual fallout situation, but have the advantage that they were done on man and need not introduce the further perturbation of the extrapolation to man of data derived from species other than man. During the past ten years there have become available several studies on the effects of single large doses of radiation to man carried out in the course of the treatment of malignant diseases and also as a means of suppressing the immune mechanisms preparatory to organ transplantation.

The studies of dose relationships to irradiation responses ranging from malaise and anorexia to death were carried out by Lushbaugh and colleagues (1) on 93 patients irradiated for therapeutic purposes in the Oak Ridge Institute for Nuclear Studies (ORINS) total-body irradiation facility and 7 nuclear radiation accident victims who were treated at the ORINS Medical Division. All of the ORINS patients had either an inoperable malignancy or a blood dyscrasia for which they have received previous conventional therapy and the disease process was in relapse at the time of their exposure. It must be noted, in an analysis of the results, that only the seven men exposed in the radiation accident were normal; the others were suffering from otherwise lethal diseases. Eighty-four patients were exposed to 50, 100, or 300 R of ^{137}Cs gamma radiation at the rate of 0.75 to 1.6 R/min. The nine others were exposed to opposing-beam irradiation with ^{60}Co gamma radiation. The dose in R in air was converted to midline epigastric rads by using a conversion factor of 0.66. Seven quantal clinical responses were studied, namely, anorexia, nausea, vomiting, diarrhea, fatigue, listlessness, and death.

The resulting 100 midepgiastric doses were found to be clustered in four groups of unequal numbers of cases. The arithmetic and geometric means of each group were used for the subsequent linear and logarithmic line-fitting programs. Probit analysis of Effective Doses (ED_{50}) using arithmetic dose yielded the following: for anorexia 82 $\pm$ 32 rads ($S.E._m$), nausea 130 $\pm$ 20, vomiting 173 $\pm$ 18, fatigue 136 $\pm$ 36, diarrhea 194 $\pm$ 19, and death 281 $\pm$ 44. Of course, the clinical picture in this series of studies could conceivably be colored by signs and symptoms related to the patients' underlying diseases. In order to attempt to obviate this possible perturbation Lushbaugh et al (2) extended their studies by the addition of 63 more cases and adjusted the patients' responses for

the natural incidence of the response using Abbotts' formula. The percentage of response due to natural incidence was arbitrarily assumed to be the Y intercept (a) at zero dose of the probit regression line fitted linearly to the uncorrected data. On the basis of the addition of the 63 cases the normal ED_{50} arithmetic distribution for two end points, vomiting and death, now become: vomiting uncorrected 198 $\pm$ 16 rads, corrected 214 $\pm$ 22 rads or 325 $\pm$ 33 R; and death uncorrected 243 $\pm$ 22 rads, corrected 251 $\pm$ 28 rads or 381 $\pm$ 43 R. The authors stated that "extrapolation from these data for estimation of higher probability levels of response (ED_{95}) must be restricted because these studies contain few observations at high dose levels. Our analysis appears to show that disease produces negative skewness in the apparent radiation dose-response relationship." The 95% confidence intervals for the quantal postirradiation response, death within 60 days based on the 100 case series and uncorrected yield a lower estimate of approximately 210 rads and an upper limit somewhat in excess of 400 rads. It would seem that on the basis of this careful study done on man no violence is done to the Report No. 29 assumption of a 60 day LD_{50} for man in the domain of 450 R or 300 rads. Nor does the dose estimated to evoke the response, vomiting, seem to be astray.

An excellent summary of the effects of fractionation of radiation dose on skin effects, namely, erythema and moist desquamation, as well as a discussion of the relationship between total-body versus partial-body irradiation on haematologic effects is contained in the report of the Space Radiation Study Panel of the National Academy of Sciences--National Research Council (3). Although these discussions are germane to the problem at hand, I prefer to direct our attention to observations which more closely mimic the actual fallout situation of irradiation of man. Martinez and colleagues (4) have reported in detail the effects of continuous total-body irradiation of five members of a family who were unwittingly and for the most part continuously exposed to ^{60}Co gamma radiation.

The survivor of the exposure of five persons, a male aged 30 years was exposed over a period of 106 days to a radiation dose estimated to range between 984 and 1,716 rem, and received the smallest exposure in this incident. On the thirty-sixth day after initiation of exposure, which was at a dose rate which was estimated at between 9.3 rem/day, to 16.2 rem/day, he developed fatigability and blackening of the nails of the fingers. One hundred and seventy-eight days after the onset of exposure the patient had a leukopenia of 2,200 cells/mm^3 and a platelet count of 190,000/mm^3. Four months later his leukocyte count was 5,400 and platelet count 190,000. The bone marrow biopsy done at the time of greatest peripheral blood cell depletion showed diminished cellularity and also diminished megakaryocytes. By the 204th day after the onset of exposure and 55 days after its cessation the bone marrow biopsy was reported as normal except for discrete "alternations in the megakaryocyts". If one were to attempt a correlation of the clinical and haematological picture with that seen in the acute total-body radiation accident cases reported in the past, he would not be far afield if he estimated that this corresponded to a total acute dose of no more than 200 R or 130 rad. Certainly from the time course to death in two other of the cases in this accident and in the clinical picture leading to recovery in the previously described one, there is confirmatory evidence in man of recovery and of the mollifying influence of low dose rate.

In the past several years a vast amount of data have been gathered concerning the late effects of radioelements concentrated in the human skeleton and

thyroid. An extended discussion of these effects is in order at this time. In the studies carried out by Conard and his colleagues (5) eleven and twelve years after the fallout exposure of the inhabitants of Rongelap and Utirik Islands especial attention has been paid to the effects of the ingestion of fallout on the thyroid gland. The authors state that "in addition to the ^{131}I the isotopes ^{133}I, ^{135}I, and to less extent ^{132}I contributed significantly to the thyroid dose. The only direct data on the Rongelap people are the radio-chemical analyses of pooled urine samples taken 15 days and longer after the fallout. Three separate estimates have been made of the dose from the radioiodines to the thyroid glands of adults exposed on Rongelap: 150 rads (from direct measurement of urinary ^{131}I), 100 rads (by indirect measurements on pigs removed from Rongelap plus Marshallese urinary excretion data), and 160 rads (based on recent recalculations of early data). On the basis of a consideration of the various differences in size of the thyroid, differences in turn-over rates, and so forth, the radiation dose from the various radioiodines to the thyroid of children less than four years of age was estimated to be about 1000 rads, with a range of 700 to 1400. The glands of adults and children received an additional 175 rads from external gamma radiation.

Until 1963 no thyroid abnormalities were detected in the exposed or control populations. However, beginning at 9 years after exposure a total of 18 cases of abnormalities of the thyroid have been detected. Nodules of the thyroid were found in 16 cases and 2 had hypothyroidism with growth retardation, but with no nodules. All occurred in the more heavily exposed Rongelap people except for one in the less exposed (Ailingnae) group. Of the 16 cases with nodules, 11 have had surgical procedures carried out on their thyroids. The glands for the most part demonstrated multiple adenomatous nodules and cysts. One patient, a 42-year-old female who was 30 years of age at the time of exposure, had a mixed papillary and follicular carcinoma of the thyroid with metastases to the regional lymph nodes. The authors state that it is noteworthy that the preponderance of thyroid abnormalities have occurred in children exposed at less than 10 years of age and only in the more heavily exposed group (15 of 19 children, 78.9%). No cases with thyroid abnormalities were detected in the children in the lower exposure groups of the same age range from the other islands or in the 61 unexposed Rongelap children. Two adults with thyroid nodules were noted in the more heavily exposed Rongelap group and one in the Ailingnae group. In the Utirik and unexposed populations a low incidence of thyroid nodules was found, and these occurred only in the older age group.

Let us now turn our attention to a consideration of the state of knowledge concerning the late effects of the deposition of the bone-seeking radioelements in the skeleton of man. Until the present it has not been possible to relate the build up of ^{90}Sr in the skeleton of man from weapons-testing or the past war time use of nuclear weapons either with an increase in leukemia or with an increase in the incidence of malignant bone tumors to a level that could be sorted from the "natural incidence." However, a large mass of evidence and material has accumulated during the past 20 years in the United States and in other countries concerning the quantitation,excretion rates, and late effects of the deposition of ^{226}Ra in the skeleton of man. Three major projects have been under way in the United States and I shall describe the findings of my colleagues and myself at the Argonne National Laboratory and the Argonne Cancer Research Hospital in Chicago (6). This group of radium-bearing patients is composed of those persons who worked as radium dial painters in the State of Illinois in the 1914-1930 period, and a group of patients who had been administered radium orally or parenterally as a medication for a wide variety of diseases during the period approximately 1920-1933. The incidence of radium-induced malignant tumors and

blood dyscrasias was related to current or preterminal radium burden measurements for a series of 293 persons. The 46 malignant diseases observed included 23 bone sarcomas, 16 neoplasms of the skull (principally mastoid and paranasal sinus carcinomas), and 7 blood dyscrasias including leukemia. The current or preterminal body burden of ^{226}Ra ranged from 0.60 microcuries to 10.70 microcuries. Another patient with a body burden of 0.13 microcuries had a peridontal tumor thought by some to be a bona fide squamous cell carcinoma and by another to represent a tumor of the odontogenic apparatus of questionable malignancy.

Time does not permit a lengthy analysis of the intricacies of dose estimation to the bone and tissues sensitive to induction of tumors within the bone or immediately adjacent to it. However, as a gross approximation it can be noted that in a person bearing a 1 microcurie body burden of ^{226}Ra at 40 years after the acquisition fo the radionuclide the yearly radiation dose to the diffusely labeled bone will be of the order of 20 rads/year with a dose rate to the "hot-spots" or sites of concentration in certain Haversian systems of the order of 2000 rads/year. The cumulative rads for the skeleton as a whole will be in the domain of 2000-2500 rads in the previous 40 years.

The incidence of bone sarcomas uncorrected for age in our former dial painters is approximately 250 times the expected incidence in the United States for the year 1959. The incidence of tumors of the mastoids and paranasal sinuses approximates 450 times the expected incidence.

The large body of data which has been accumulated concerning the late effects of the one bone-seeking radioelement cannot easily be extrapolated to the fallout situation and ^{90}Sr. In a report published recently on behalf of the International Atomic Energy Agency and the World Health Organization (7) the discussion concerning dose-response relationships states "The risk estimates in Table 1 are mainly based on information from radium in a few hundred individuals. It is not appropriate to extrapolate risk estimates, since the dose-response relationship is probably not linear." The report proceeds, "Radium and strontium absorbed into blood are eliminated from the body at different rates. From a comparison of time integral of internal contamination during a period 1 to 30 years after intake it can be estimated that 3 microcuries of ^{90}Sr at the end of 1 year give the same integrated exposure to bone as a terminal content of 1 microcurie of radium at the end of 30 years. Thus a terminal body burden of 1 microcurie of radium is considered equivalent in biological effect to 60 microcuries of ^{90}Sr in the skeleton one year after intake. It can be calculated that this corresponds to an intake of 1500 microcuries of ^{90}Sr by inhalation or 2000 microcuries by ingestion." These statements, however, do not include estimates of the effect of early high dose rate on the oncogenic processes.

Let us now look at the data concerning body burdens of ^{90}Sr in the Marshallese. Conard and his colleagues state that in 1958, four years after the primary exposure, analyses of bone samples of one of the men who died showed a body burden of 3.7 nCi ^{90}Sr. "The mean level urinary excretion of ^{90}Sr was 7.2 pCi/l or 14% higher than measured in the 1959 medical survey. In 1962 the mean urinary ^{90}Sr level was 114 pCi/g Ca, giving an estimated body burden of 12.0 nCi. Analysis of bones from the deceased Rongelap woman (1962) gave an estimated body burden of 11.4 nCi. It thus appears that body burdens of ^{90}Sr have reached equilibrium with the environmental ^{90}Sr. Little or none of the present body burden of the exposed group can be considered residual from their initial exposure, since little difference has been noted between the body burdens in exposed and unexposed populations living on Rongelap Island."

On the basis of the incomplete summary of human radiation effects which I have presented, what tentative conclusions can be drawn which bear on the clinical consequences of protracted exposure to fallout? First, no evidence has come to light which would lead me to assume that the 60 day LD_{50} for man for an acute exposure to fission product gamma radiation is greater than 450 R or 300 rads, and it may be in the domain of 250 rads. The Mexican experience reinforces the evidence for man, well known for the experimental animal, of the presence of recovery and the mollifying effect of low dose rate. Parenthetically, the clinical picture demonstrated by the survivor in the Mexican experience is not a bad fit for an acute radiation dose in the domain of 200 R, which, if the estimates of total dose incurred are not far afield fits closely the total protracted dose modified by the recovery rate factors used in Report No. 29. In addition, the fit is also good for an effective dose calculated by dividing the total absorbed protracted dose by the cube root of the time in days over which the dose was delivered.

Most disturbing is the evidence collected in the Marshall Island study of the especial radiosensitivity of the thyroid of the young. Although no malignant tumors have been seen in the thyroids of those exposed to the radioiodines from fallout when younger than 10 years, the degree of morphological alteration is striking, the incidence is probably 100%, the evidence for severe metabolic alterations in at least 2 of the children definite, and the disability severe. The true incidence of malignant thyroid tumors in the children attendant on theis radiation dose will not be known because of thyroid surgery and the prophylactic administration of l-thyroxine. We have, therefore, clear-cut evidence of severe thyroidal disease ensuing from the ingestion of radioiodines falling out in a field which produced an acute external radiation dose of 175 rads. The late effects to the adult thyroid probably will not be seen for some time to come, although one thyroid carcinoma has already been observed and treated. The necessity for planning for thyroid blockade by various means to prevent or minimize the uptake of the radioiodines should be apparent to all.

What can be said concerning the hazards of the ingestion of ^{90}Sr during existence in a fallout field ? As the pattern of dose-response relationships develops in the radium-bearing patients, and as the studies on the relative radiotoxicities of various bone-seekers in the large animal studies still under way become available, more precise estimates of risk may come to hand.

A critical gap in our knowledge is in the area of possible radiosensitivity of the skeleton of the child to tumor induction. Until this information becomes available, and it may never, our attention must be directed toward means of reducing and keeping to a practical minimum the ingestion by the child of the long-lived bone-seeking radioelements and ensuring that important nutritional elements are not at the same time removed from the diet by these remedial procedures.

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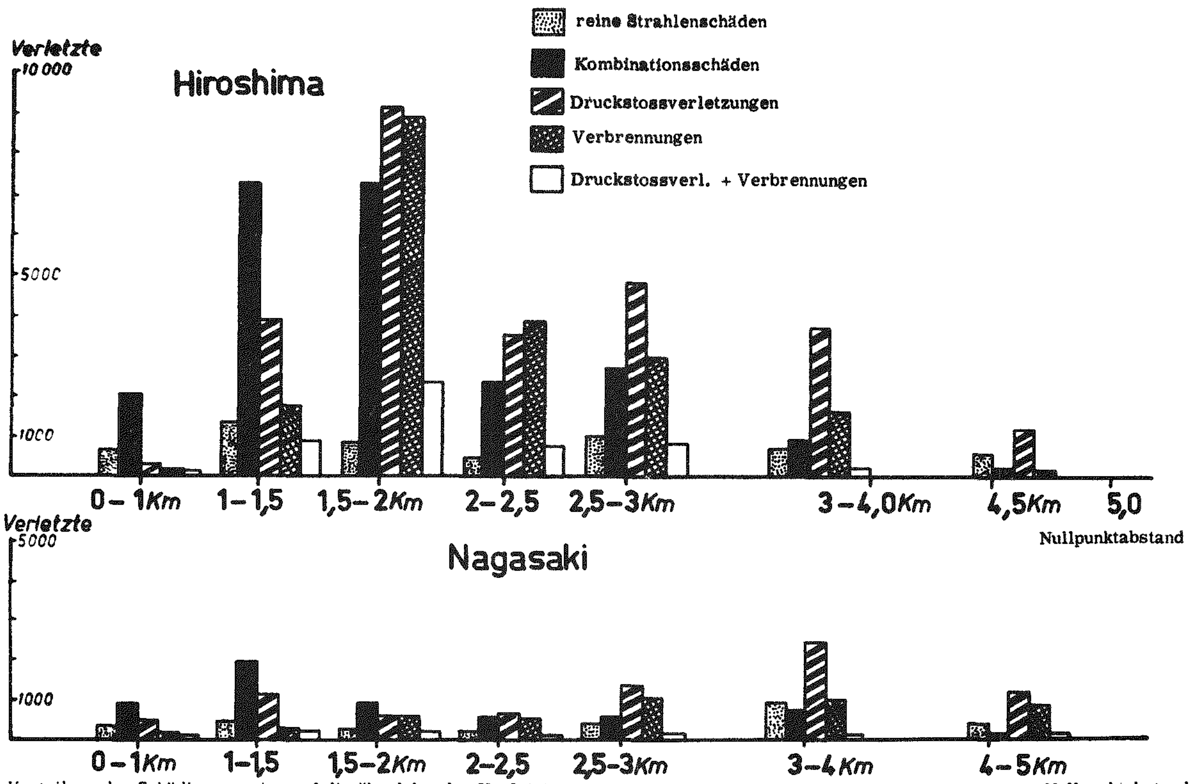

Abb. 1: Verteilung der Schädigungsarten auf die überlebenden Verletzten aus Hiroshima (72000) und Nagasaki (25000)

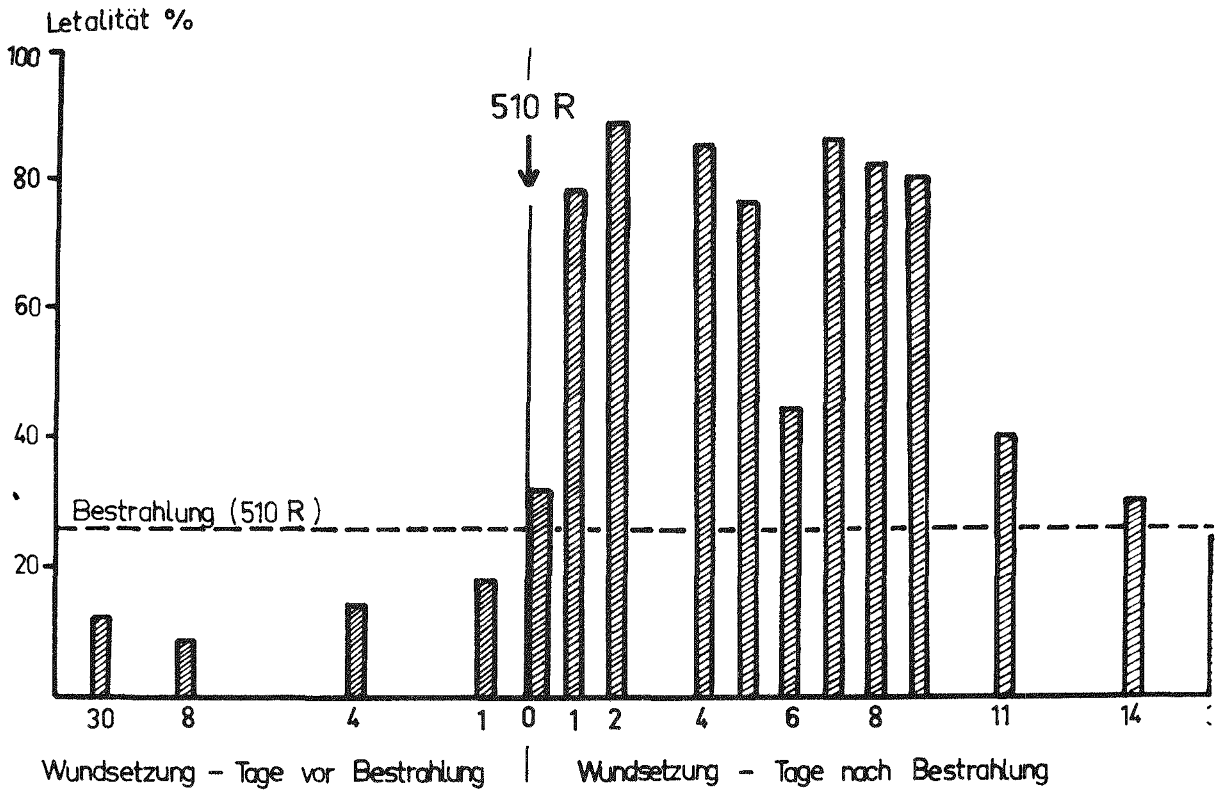

Abb. 2: Letalität männlicher Mäuse des Stammes "Radiologisches Institut Freiburg" in Abhängigkeit vom Abstand zwischen Ganzkörperbestrahlung (510 R) und Erzeugung einer offenen Hautwunde, sowie von der Reihenfolge beider Traumen.

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EVALUATION OF LARGE ANIMAL STUDIES ON RECOVERY FROM RADIATION INJURY

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2.5

The advice given in the National Council on Radiation Protection and Measurement Handbook No. 29 entitled "Exposure to Radiation in an Emergency" has been widely used and abused by Civil Defense planners since its publication in 1962. Some of the abuses will be discussed by Dr. George V. LeRoy in his presentation here. I call to your attention a lecture that Dr. LeRoy presented at the Conference of the NATO Civil Defense Committee, in Paris on June 20-21, 1961 just at the time that Handbook No. 29 was being prepared for publication ("Emergency Exposures", G.V. LeRoy in Exposure of Man to Radiation in Nuclear Warfare, edited by J. H. Rust and D. J. Mewissen, Elsevier, Amsterdam (1963)). In this lecture and in the discussions that followed he presented lucidly and in detail the rationale for Handbook No. 29. I commend it to your attention.

Since the appearance of the document there have been criticisms, some valid and some not, and an expressed need for a reevaluation of the concepts and recommendations in Handbook No. 29. I won't detail the criticisms but do recognize the need for reevaluation periodically of a document followed by a copious flow of new research data.

The Civil Defense situation, with respect to the ambient radiation due to fallout from nuclear weapons, is indeed a very special exposure mode. A first approximation for a Civil Defense Ambient Radiation Fallout Model suggests an initial brief exposure at a relatively high rate, i.e., 1/4 - 1/3 of the median lethal dose (MLD or LD 50/30), followed by a protracted exposure at 20 R/day down to 1 or 2 R/day, possibly even less. This roughly parallels the commonly accepted fallout power law decay constant of $t^{-1.2}$. I have just completed a rather extensive search of the relevant literature and can find no designed studies that completely follow this model with large or small animals. There are a few animal studies that can, in a general way, be considered to follow the protracted, or $b\dot{D}$, portion of the Handbook No. 29 formulation but they are not completely satisfactory.

This failure to develop such data is a surprising state for an alert scientific community to accept and a sad commentary upon those who seek and use data and support research to develop such data. It demands our immediate attention.

The data used to develop Handbook No. 29 came from many sources but very important in developing the concept was the data from rodents. There has been some objection to this. It has been suggested that large mammal data might be better. It was my task to study the large animal data and to determine whether or not it was better for reevaluating the concepts used in Handbook No. 29. I found many items of interest and I'll try to select from those data items which will describe the state of that information.

My most serious objection to much of the data that I have found is that life shortening or death, or a specific disease such as leukemia, are the parameters most commonly measured. These are clearly long-term end points that are not in the real interest of Civil Defense planners who are concerned for human survival. In spite of this objection we are often forced to use these data.

Another objection to the data is that so much of it is of the "split-dose" variety. In this test system there is an initial conditioning radiation dose which, after a rest period, is followed by a second series of exposures given either in a short time, e.g., a LD 50/30 determination, or by a protracted series of exposures until death. The change in the magnitude of the second exposure as a function of time is considered to be the slope that measures the recovery from the initial radiation exposure injury. There are several objections to this method. One important one is that there is no assurance that the second exposure is a valid test for the residual radiation injury or the recovery from the initial exposure.

More formal is the following criticism

> ". . . an injury curve is governed by two rate constants, for buildup and recovery of injury, respectively. The formal 'recovery rate' given by split-dose procedures is a function of both parameters, but is numerically closer to the smaller, which could be the buildup rather than the tissue recovery constant. Hence, the work on recovery rates done to date is equivocal, since it attempts to describe with one rate parameter a process that in its simplest form must have at least two."
> G. A. Sacher and D. Grahn in Survival of Mice Under Duration-of-Life Exposure to Gamma Rays. I. The Dosage-Survival Relation and the Lethality Function. J. Nat. Cancer Inst. 32: 277-310 (1964).

In the Civil Defense fallout situation it is generally believed that the principal hazard will be from the total body exposure derived from the ambient radiation of the radioactive fallout. Most investigators and students of the problem have largely ignored the contact exposure due to beta radiation as an immediate life jeopardizing event. It does, however, have some long-term consequences that have, in the case of cattle, been severe. These should be considered. In "Damage to Livestock from Radioactive Fallout in the Event of Nuclear War" (NAS-NRC publication No. 1078-1963), it was reported that three of the herd of Hereford beef cattle kept at the University of Tennessee for 15-17 years after being exposed to the fallout from the first atomic weapon detonated at Alamagordo, New Mexico (in 1945) eventually developed squamous cell carcinoma in the "burned" areas of their back. Later a fourth animal was discovered with the same cancer. There were approximately fifty animals in the original herd. Due to an intercurrent disease several had to be killed so no statement regarding the rate of occurrence of the cancer can be made. It was estimated at the time of the exposure that an average skin dose of 39,000 rep was received over 10% of their body surface and that the total body gamma ray exposure they received due to the fallout was about 140R.

A photograph of the last surviving female, with the last of her long series of calves, taken at an estimated age of 24 years, shows the severity of the back lesion and the vigor of her offspring. None of her cohorts showed any reduction in fertility or viability of offspring. These animals were all exposed to ambient radiation that most clearly resembles the Civil Defense fallout model of any of the large animal data available. They responded to all later-life stresses in a manner that was not different from a control group except for the squamous cell carcinoma of the skin of the back. In view of this it seems likely that beta radiation from fallout will not appreciably alter the life span of those exposed. Man, of course, can take defensive measures which should be of added help in his protection. We must not overlook this.

It seems likely that the total body gamma ray exposure of these cattle did not exceed thirty days, probably much less for the substantial portion of their exposure. We can therefore somewhat cautiously compare their life time response to some of the gamma ray exposed RF mice in the recent study of Upton and his colleagues ("Late Effects of Fast Neutrons and Gamma Rays in Mice as Influenced by the Dose Rate of Irradiation: Life Shortening" A.C. Upton, M.L. Randolph and J.W. Conklin, Radiation Research 32: 493-509 (1967)) in Table 1. I will not refer to rodent data again.

These mouse data certainly suggest that exposures administered for relatively short periods of time, at relatively low doses and in the "Civil Defense range", are without any consistent life shortening effect in mice. Even though the Hereford cows mentioned were in a study that was confounded by an intercurrent infectious disease, their life, like the mice did not appear to be substantially lessened even with the occurrence of the metastasizing squamous cell carcinoma due to the beta burn of the skin. Admittedly the cattle had an effective dose that was less than the 200 ERD which is given as the maximum in Handbook No. 29 probably an exposure equal to an ERD of 70-8oR if one uses only the aD_{Θ} multiplier. In both animal species the dose discussed is certainly not large enough to noticeably shorten their lives. These doses approach the bounds of exposure one would like to keep man within and from that standpoint the data, scant as they are, are instructive and relevant.

I have already mentioned and discussed the split-dose technique for measuring recovery from an initial exposure and have told you of my objection, namely, there is no assurance that the test with a second radiation exposure truly measures recovery. Perhaps it will be of profit to examine a few of the studies that have come to my attention.

One study with sheep at the University of Tennessee (U. S. G. Kuhn, D. A. Brown and F. H. Cross, unpublished data) uses the method of an initial dose followed by a second test exposure given in daily dose until death. The data are presented in Table II.

What is most interesting and disturbing in these data is that there seems to be so little difference in the absolute total dose required to kill the sheep. One can conclude that the injury was absolute and that there was no recovery even after 65 days. The use of the brief exposure, aD_{Θ}, and the protracted exposure, $b\dot{D}$, multiplying factor which assumes recovery from radiation injury does not change the data for our purposes. This ambivalence in the data is most disturbing.

Table 1

Longevity of RF Mice Exposed to Total Body Gamma Rays

Dose Rate (R/d)	Mean Dose (R)	Exposure Duration (d)	Life Shortening (d)*
		Females	
0	0	0	0 (582)
5.2	104	20	17
14.5	101	7	-16
30.5	305	10	- 2
102	306	3	9
		Males	
0	0	0	0 (576)
5.2	148	30	-29
14.7	153	10	- 6
30.5	305	10	-26
78.7	315	4	40

*Negative values are actually mean life spans greater than the control.

Table II

Killing Dose for Repeatedly Irradiated Sheep Preexposed to 400R Total Body Irradiation

Rest Period (d)	Second Exposure (100R/d)	Total Killing Dose(R)	$\underline{aD_o}$ (R)	$\underline{b\dot{D}}$ (R)	Estimated (ERD) (R)
0 (control)	1950	1950	0	1200	1200
0	1560	1960	400	900	1300
5	1480	1880	390	900	1290
10	1890	2290	350	1200	1590
15	1490	1990	300	900	1200
30	1780	2180	225	1100	1325
65	1700	2100	110	1000	1110

Trum et al. ("Radiation Injury and Recovery in Swine", B.F. Trum, J.N. Shively, U.S.G. Kuhn and W.T. Carll, Radiation Research 11: 326-342 (1959)) have made a somewhat similar study with swine. They gave conditioning doses ranging from 360-610R ninety days before protracted test exposures at 50R/day. Their data are presented in Table III.

Table III

Killing Dose for Continuously Irradiated Swine Preexposed to 360-610R Total Body Irradiation

Initial Dose (R)	Mean Secondary Killing Dose(R) (50R/d)	$\underline{aD_o}$ (R)	$\underline{b\dot{D}}$ (R)	ERD Range (R) (aD_o + $b\dot{D}$)
0	10,200	0	2500	2000 - 3500
360	9,950	72	2500	2250 - 3000
425	9,050	85	2400	2000 - 3000
484	7,650	97	2350	1850 - 2500
547	7,750	110	2375	1900 - 2750
610	6,850	120	2100	2000 - 2650

The evidence here is unmistakable that swine are quite resistant to protracted total body exposure given at 50R/day even after a conditioning dose of near LD 50/30 proportions. There is also evidence that the magnitude of the initial dose has a substantial influence upon the ability of the swine to survive the second radiation insult. I have taken the liberty of using the Handbook No. 29 ERD multipliers to correct for recovery from both the initial and secondary exposure. Of all of the data I have at hand, that has been treated in this manner, it is the only set in which the summation of these multipliers gives an essential equal value for all exposure modes. This is quite apparent when one observes how the ERD range values overlap at all dose levels. If these were the only data available I would have had to conclude that swine follow the Handbook No. 29 best of all large animals. I must add, however, that I have serious reservations about this.

Another split-dose approach was the measurement of residual injury and recovery of dogs following a conditioning initial radiation exposure of 217R with a LD 50/30 test. The data were presented by Ainsworth and Leong ("Recovery from Radiation Injury in Dogs as Evaluated by the Split-Dose Technique", E.J. Ainsworth and G.F. Leong, Radiation Research 29: 131-142 (1966)). Selections from this study are presented in Table IV.

Table IV

LD 50/30 in Total Body Irradiated Dogs Exposed to an Initial Dose of 217R

Rest Period (d)	LD 50/30 (R)	95 % CI (R)	aD_o (R)	Estimate of Total Dose (R) (aD_o+ LD 50/30)
0	319	302-341	0	319
1	107	81-131	217	324
3	210	190-226	217	427
7	253	217-292	200	453
14	313	276-341	165	478
20	361	330-385	150	511

If one inspects the LD 50/30 column he sees that for the first 2 weeks after the initial exposure of 217R that there must have been a residual injury which made the dogs more sensitive to total-body radiation. But thereafter, at 20 days, the dogs are quite resistant to the test treatment. Again I have taken a liberty and added the LD 50/30 dose to the aD_o corrected initial dose. This tends to accentuate the difference and trend. It certainly suggests strongly that these two items cannot not be summed and still keep within the conceptual bounds of the Handbook No. 29. It is strongly suggested that the conditioning exposure makes the animals more resistant to subsequent exposures. I believe that this is an untenable position to accept.

From the same research group a study, using the same technique with sheep exposed to an initial dose of 165R and tested at different rates with an LD 50/30 method, has been published ("Injury Accumulation and Recovery in Sheep Exposed to Protracted Cobalt-60 Gamma Radiation", G.E. Hanks, E.J. Ainsworth, G.F. Leong, D.S. Nachtwey and N.P. Page, Radiation Research 29: 211-221 (1966)). These data are presented in Table V.

Table V

LD 50/30 in Total Body Irradiated Sheep Exposed to an Initial Dose of 165 R

Rest Period (d)	LD 50/30 (R)	95 % CI (R)	$\underline{aD_o}$ (R)	Estimate of Total Dose (R) (aD_o + LD 50/30)
		Control		
0	237	215-257	0	237
		Second Exposure at 0.5R/hour		
0	268	224-328	165	433
31	245	214-284	90	335
		Second Exposure at 1.85R/hour		
0	162	141-182	165	327
15	342	303-382	125	467
		Second Exposure at 3.9R/hour		
0	133	106-162	165	298
7	218	185-270	150	368
27	210	187-236	100	310

These data are confusing but seem to indicate that dose rate may be important in determining what response there may be with the secondary exposure. It further complicates an already complex picture and certainly undermines any belief that a second radiation challenge measures recovery from a prior radiation exposure. Perhaps most disconcerting is the apparent rapid and long-lasting "over-recovery" from the initial exposure to 165R in sheep.

The data of Rehfeld _et al_. ("Response of Beagles to Repeated, Near Lethal, Doses of Co^{60} Gamma radiation", C.E. Rehfeld, C.M. Poole, W.P. Norris, and D.E. Doyle, Annual Report, Biological and Medical Research Division, Argonne National Laboratory, ANL-7278 (1966), pp. 106-108) adds further to the confused situation. These data are summarized in Table VI which is modified from the authors presentation for our purposes.

Table VI

The Fate of 23 Young Adult Dogs After 3 Successive Total-Body Cobalt-60 Exposures

Exposure (R)	Dogs Exposed	Dogs Dead	% Killed	Time of death (d)	Range
300 (Ave)	23	4	17	26	(19-29)
		rest period of 99 days			
300 + 275	19	8	42	25	(19-32)
		rest period of 85 days			
300 + 275 + 275	11	6	55	28	(23-40)
		rest period of 300 days			
	5	dogs still surviving			

One cannot say that the dogs after 99 and 85 days had completely recovered but they were certainly approaching that state, if one may use the per cent killed as a fair estimate of the LD 50/30. It almost seems as if the prior treatments are without subsequent influence.

So, in summarizing the data of the "split-dose" variety the best that can be derived from it is that it says, "no recovery", "some recovery", "much recovery", -- in fact in some cases "super-recovery", and finally I add "equivocation". It is in truth data that are unusable in developing guides for the Civil Defense situation. Perhaps this is the moment to turn to other writers for a pertinent criticism and warning. In a recent public presentation by Grahn and Sacher ("Fractionation and Protraction Factors and the Late Effects of Radiation in Small Mammals", Douglas Grahn and G.A. Sacher at the Symposium on Dose Rate in Mammalian Radiation Biology, Oak Ridge, Tenn., April 29-May 1, 1968--to be published) they have warned that "Obviously, one cannot dichotomize the data into "short term" and "long term" processes since the manifestations of and the recovery from injury is a continuous process". This is the difficult position one finds oneself in attempting to sum this great variety of data, whether it is from a single exposure or many exposures, or possibly at a low rate or high rate. How one can sum the contradictory data developed, even if there was no warning of the dichotomy hazard, is more puzzling. The final burden is to extrapolate it to man.

There are some studies of another type which may be helpful in the protracted portion of the Handbook No. 29 equation, <u>bD</u>.

Data presented by Norris et al. is instructive and is given in part here (Table VII) ("The Response of Beagle Dogs to Continuous Exposure to Co^{60} Gamma Rays", W.P. Norris, T.E. Fritz, C.M. Poole, F.S. Williamson and C.E. Rehfeld, Annual Report, Biological and Medical Research Division,

Argonne National Laboratory, ANL 7278 (1966), pp. 102-106). One might expect that protracted exposures would differ in magnitude with different exposure rates if the recovery from an exposure follows the concept of Handbook No. 29. However, from these data it is clear that the recovery of these dogs did not follow the prediction. On the average they required the same killing dose whatever the rate. The low exposure rate here must then be considered to be more damaging and to be followed with less recovery than the faster exposure rate. Such a suggestion is contrary to and does not support the hypothesis of Handbook No. 29. I call your attention to the decreasing values in the % of total dose column. This is an empirically derived value which is $b\dot{D}$/mean dose X 100. I want you to compare and contrast this with that to be seen in the next data to be examined.

Table VII

Response of Dogs to Protracted Total-Body Cobalt-60 Exposure

Exposure (R/d)	Mean Survival (d)	Range (d)	Mean Dose (R)	Approximate $b\dot{D}$ (R)	% of actual dose
72	26	23-29	1872	1300	69
50	38	32-57	1906	1100	58
35	53	41-74	1864	875	47

Table VIII

Response of the Ass to Protracted Total-Body Cobalt-60 Exposures

Exposure (R/d)	Mean Survival (d)	S. D (d)	Mean Dose (R)	Approximate $b\dot{D}$ (R)	% of actual dose
400	8	1	3330	1400	42
200	14	3	2810	1800	64
100	23	1	2330	1400	60
50	30	3	1510	900	72
25	63	13	1575	1250	79

Some years ago a series of studies was made with the Mexican burro (also called the ass Equus asinus). This work is summarized and discussed by Mewissen et al. ("A Formula for Chronic Radiation Dosage versus Shortening of Life Span, Application to a Large Mammal", D.J. Mewissen, C.L. Comar, B.F. Trum and J.H. Rust, Radiation Research, 6: 450-459, (1957)). It is important to first point out that this paper supported the Blair hypothesis upon which much of Handbook No. 29 is based. These data are presented in Table VIII.

What is most interesting is the comparison of the response of the dog and the ass to the same general range of protracted exposures. I call your attention to the 72, 50 and 35R/day values for the dog and the 100, 50 and 25R/day for the ass. Certainly no one will doubt that these doses are in the same range. What is disturbing is that the percentage of actual dose as it relates to bD dose, in the last column, for the dog decreases with decreasing dose while with the ass it increases with decreasing dose. They should not follow opposite paths if the ERD concept is valid. When data of this type derived from large animals must be translated to man then one would be sorely pressed to choose between these data. In spite of some seeming areas of agreement one can be led to different conclusions regarding recovery from protracted exposure. If, as Mewissen et al. have suggested, their data support the Blair hypothesis, and inferentially the Handbook No. 29 concept, then the data of Norris et al. certainly does not support the Handbook No. 29 concept. This is not a judgement upon the quality of the data but a statement about the dilemma of the data user.

Finally, there are two other studies that must be called to your attention. I do so because they do not measure life shortening, leukamia or acute death. A paper by Baum, Davis and Alpern ("Effect of Repeated Roentgen or Neutron Irradiation on the Hematopoietic System", S.J. Baum, A.K. Davis and E.L. Alpern, Radiation Research 15: 97-108 (1961)) is one of those pertinent and adds to the confusion of those who believe that there is recovery from a radiation insult. Baum et al. measured the effect of a radiation exposure upon the recovery of hematopoiesis, a non-fatal parameter. Pertinent selected data are presented in Table IX.

Table IX

Red Blood Cell Iron Incorporation (Est.) and Hematocrit Values in Dogs Exposed to Repeated Doses of 150 Rads of X-rays

Number of Exposures (150 rads at 90 day intervals)	R. B. C. Iron (Est.) Incorporation (% of dose)	Hematocrit (%)
0	93	44.1
1	70	40.7
2	59	40.2
3	50	40.2
4	43	41.0

The estimate of the erythrocyte iron incorporation was made by me from Figure 1 of the paper of Baum et al. and shows clearly that there has been a disturbance in the maturation of erythrocytes while the relatively stable hematocrit is little altered by the series of radiation exposure. If nothing else this plainly indicates the danger in measuring the degree of residual radiation injury from a randomly chosen end point, for in items so closely allied as these, there is quite different information derived from the parameters measured. More important is the clear evidence that bone marrow injury is accumulated and is not being repaired. The red blood cells in circulation are unaware of the problem.

There is presently a study being conducted by D.A. Brown and colleagues at the University of Tennessee-Atomic Energy Commission Agricultural Research Program which is designed to evaluate the physical fitness of Shetland ponies (Equus caballus) after protracted total body irradiation. Eight ponies have been exposed to 50R/week (at 25R/hrs) each week until 650R had been received. Platelets and leucocytes had by that time reached a critically low point and hemorrhagic diathesis was making an appearance. An equal number of control animals was used. Five pairs, the irradiated animal and its pre-exposured selected running mate, were started on a work program 150 days after the exposure and three pairs were kept in an exercise lot as non-working controls. The work machine was an especially designed "carousel" which, by means of a hydraulic motor and valve, can generate a graded work load. The work load of each team can be adjusted independently. The current work rate is 4×10^5 foot-pounds/hour.

Many parameters--behavioral, physiological and biochemical--have been measured. There are no differences except for one; the heart rate is slower in the irradiated team member and the recovery of the heart rate during rest periods is slower during the latter part of the working day. Interestingly however the ability to perform work is not diminished even 2-1/2 years after exposure. It is true that this exposure mode and the delay in testing is not equivalent to a Civil Defense disaster situation. It is in fact, though, a much more severe radiation exposure than one expects to encounter. It does indicate that the ability for man to perform hard physical labor may not be impaired with lesser doses, certainly in the range of a maximum of 200 ERD.

All of these confusing data make it impossible to select the correct values for extrapolation to man. Indeed the data from large animals has contributed nothing but confusion and chaos to the already difficult data situation. In spite of this the plea that studies be developed especially for the Civil Defense situation must not go unheeded. It is possible, even highly likely, that nothing better will be developed than we have at the moment. In the meantime we must use, to the best of our ability, the information derived from studies upon man himself plus that which we can reasonably infer from the large and small animal data. If we try to make a direct extrapolation from the confusing large animal data at this time we are lost. But there remains the hope that the reason for the confusion will be uncovered and we will open onto a new area of information and rational decision.

L

REEXAMINATION OF BIOLOGICAL RECOVERY RATES AND EQUIVALENT RESIDUAL DOSES

2.6

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In the event of a nuclear detonation, best estimates of the extent of injury and recovery in man following radiation exposure will be of prime importance for command decisions related to operational procedures. Although our knowledge of the pathology of the lethal radiation lesion has been greatly enhanced over the past 30 years, the lack of human data as well as large animal data make it difficult to provide meaningful recovery estimates for man. Current estimates of recovery rates for man after either acute or protracted sublethal radiation injury have been based primarily on experimental data obtained from small laboratory animals. As a result of these studies, the recovery rate from radiation injury was first described by Blair as a single rate constant, namely, a single exponential function. This formulation of a first order model for recovery from radiation injury has led to the development of the ERD (equivalent residual dose) concept to provide a more reliable prediction of the biological and medical consequences following radiation exposure in man.

Although such a generalized model for an estimation of recovery in man is useful and necessary to the operator in making decisions, it is important that its limitations are recognized. Therefore, we have attempted to systematically compare LD_{50} responses, hematological responses, and the patterns of recovery in multiple mammalian species ranging in size from laboratory rodents to large domestic animals under controlled conditions, e.g., comparable radiation quality, exposure rate, and size of the conditioning exposure (initial injury). By studying in this manner ~~the~~ radiation responses of animals representing a broad spectrum of species, it was felt that a better estimate of the recovery rate for man could be derived.

The radiation dose that will kill half the population of animals under investigation is usually expressed as 50% lethal dose (LD_{50}) within some finite time period, 30 days for small animals (laboratory rodents) and 60 days for large animals (sheep, goats, swine, burro). The radiosensitivity or LD_{50} (acute radiation exposure) for man has been estimated generally to be 400 - 600 R (roentgens). Unfortunately, there have been many situations where rad and R have been used interchangeably to describe the LD_{50} for man with no indication of the reference point where this measurement of dose was made. It is extremely important to define accurately the spatial location where the dose is measured, especially in large animal studies and this also applies to man, when there is a question of surface dose, midline air exposure or midline tissue dose. Because of depth dose considerations, the midline tissue dose expressed in rad for large animals such as the sheep or swine is approximately 60% of the midline air exposure in R. In Figure 1, the LD_{50}'s are shown for the animals which we have studied in our Laboratory. The LD_{50}'s can be separated essentially into two groups, animals with high LD_{50}'s (800 - 900 R) and animals with low LD_{50}'s (300 - 400 R). Small laboratory rodents all fall into the high LD_{50} group with the exception of the guinea pig, whereas, all the large domestic animals fall into

the low LD_{50} group. The midline tissue LD_{50} of certain large animals, e.g., swine, calculated to be approximately 60% of the midline air LD_{50} (approximately 400 R), approximates 240 rad. This midline tissue LD_{50} is in close agreement with the human data of Lushbaugh, who has estimated the midline tissue LD_{50} for cancer patients receiving whole body ^{60}Co, to be 250 rad.

Systemic Recovery After Sublethal Acute Radiation Injury as Measured by the Split-Dose Technique

The split-dose technique was used in these studies to measure the systemic recovery patterns (radiosensitivity, LD_{50}) of the individual species. This technique involves exposing animals to a known amount of sublethal radiation injury and then measuring their radiosensitivity by LD_{50} determinations at various times following this conditioning exposure. All exposures were carried out at approximately 450 - 600 R/hr. In order to directly compare the systemic recovery rates of the various species which have vastly different LD_{50}'s or radiosensitivities, an acute conditioning exposure of 2/3 LD_{50} was routinely used. This conditioning exposure causes less than 5% deaths within a 30-day period, thus precluding the possibility that only the more radioresistant animals were being tested.

In Figure 2 the recovery patterns for the mouse, the rat, and the dog are shown. Although the LD_{50} for the dog is much lower than that for the mouse and rat, the recovery pattern for these three species can be fitted to a single exponential. However, because of the departure of the rat and dog data from the fitted line, it is also possible that the recovery curves for these two species could also be adequately fitted assuming zero order kinetics. Other evidence by us, although not shown here, indicate that the dog becomes radioresistant at 20 days following the conditioning exposure.

The hamster shows an initial shoulder of little or no recovery at 3 days followed by rapid recovery approximating 80% of the initial injury by 7 days. However, by 12 days the hamster has become radiosensitive to the extent that the animals appear to be only 30% recovered from the initial injury, and by 20 days the animals are again 80% recovered (see Figure 3). A similar recovery pattern was observed for the rabbit with the exception that the initial 3-day shoulder was not observed, and the times for maximum recovery and increased radiosensitivity occurred slightly later than that for the hamster (see Figure 3).

For the large animals, the sheep, the goat, and the burro, all show a relatively slow early recovery phase, whereas, the pig recovers much like the small rodents with a recovery half-time approximating 2 - 3 days during the early phase. Since our recovery data are most complete for the sheep and the pig, our discussion will be confined primarly to these two large animal species. The sheep shows an initial shoulder of little or no recovery for the first 11 days after the initial injury followed by rapid recovery resulting in radioresistance approximating 140% of the LD_{50} of unconditioned animals at 16 days. However, this is a transient phenomena and by 24 days the sheep show approximately 25 - 30% remaining injury which probably represents the nonrecuperable fraction (see Figure 4). The pig shows no initial shoulder and is completely recovered by 7 days after the initial injury, but they continue to over-recover or become resistant to the extent of 165% of the $LD_{50/60}$ of unconditioned animals. This radioresistance appears to persist for at least 100 days (see Figure 5). The burro data, although not as complete, shows a recovery half-time approximating 60 days and certainly indicates that this animal recovers the slowest of all the species we have studied.

Thus, we have shown significant departures of systemic recovery from exponential kinetics resulting in altered radiosensitivity in a number of species after acute sublethal radiation injury. This is in direct contradiction to the generally accepted hypothesis that recovery from radiation injury can be described as a single component linear exponential.

Injury Accumulation During Protracted ^{60}Co Exposure

The influence of exposure rate on injury accumulation during protracted ^{60}Co gamma exposure (2/3 LD_{50}) is shown in Figure 6. Sheep were placed in a ^{60}Co irradiation field and subjected to a total exposure of 165 R at exposure rates of 0.5, 0.95, 1.85, and 3.9 R/hr and their acute LD_{50}'s (660 R/hr) determined immediately after termination of the protracted exposure. Theoretically, any decrease in the LD_{50} from that of unconditioned animals would represent the amount of injury accumulated during the protracted exposure. It was found that immediately after exposure to 165 R at dose rates of 0.5 and 0.95 R/hr, there was no detectable residual injury; whereas, at dose rates of 1.85 and 3.9 R/hr, the residual injury immediately following the conditioning dose was 45 and 63%, respectively.

These data would indicate that recovery in sheep occurs during protracted exposures and that sheep apparently can recover from 165 R at exposure rates up to 1 R/hr. When exposure rates exceed 1 R/hr, injury accumulation increases as a function of dose rate. Comparisons of residual injury immediately following an exposure of 165 R delivered under acute (660 R/hr) and protracted 3.9 R/hr) conditions indicate that within this time frame, the injury is considerably greater with the acute radiation exposure. Furthermore, other experiments in our Laboratory have shown that the $LD_{50/60}$ for sheep at an exposure rate of 3.9 R/hr is approximately 495 R, as compared to an acute $LD_{50/60}$ (660 R/hr) of 237 R. Thus, the lethality response differs by a factor of 2 when the exposure rate changes from 660 to 3.9 R/hr. This is in contradiction to the ERD concept that all radiation injury received within a 4-day period is equivalent and should be considered to be an acute or brief exposure.

Systemic Recovery After Protracted ^{60}Co Exposure

Systemic recovery patterns for sheep after both acute and protracted conditioning doses of ^{60}Co gamma irradiation are shown in Figure 7. The recovery pattern after an acute exposure (450 R/hr) of 165 R has been described earlier in this report as consisting of an initial shoulder of no recovery for the first 11 days after the conditioning exposure, followed by rapid recovery extending to significant over-recovery at 20 days and then reverting to a radiosensitive state in which the LD_{50} was somewhat less than that of unconditioned animals. Comparisons of recovery patterns of animals receiving a conditioning exposure of 165 R, but at exposure rates of 3.9 and 1.85 R/hr, indicate that though the curves are qualitatively similar, there may be some important quantitative differences. Animals receiving 165 R at 3.9 R/hr show a slight shoulder which is appreciably less than that of the acute exposure situation. In fact, a significant amount of recovery has already occurred by 7 days. The time and amount of radioresistance appears to occur earlier and to be greater, respectively, than that for the acute exposure situation. Animals receiving 165 R at 1.85 R/hr appear to have even less an initial shoulder, although earlier time point determinations of LD_{50}'s must be made before definitive conclusions can be drawn.

The influence of size of conditioning exposure on the recovery pattern of sheep at an exposure rate of 3.9 R is illustrated in Figure 6. At this comparable exposure rate there is a suggestion that animals receiving a conditioning exposure of 305 R appear to have more of an initial shoulder than animals receiving 165 R, thus implying that recovery occurs slightly later at the higher exposure. In fact, the 165 R-conditioned animals are completely recovered by 7 days, whereas, the 305 R-conditioned animals are not completely recovered until 10 days.

ERD Estimate and Recovery in Large Animals

The author recognizes well the need for some formulation or model for decision making in the event of some nuclear catastrophe. In Figure 8 we have plotted ERD values taken from NCRP Report No. 29* to represent the injury remaining at times up to 100 days after an acute sublethal radiation exposure. Our sheep and burro recovery data have been superimposed on the same time scale. It can be seen that our data actually do fit rather well with the ERD estimate line, especially after the 50 - 60-day time interval following the initial injury. Although the estimated values from the ERD concept may be reasonable and applicable, the basic concept of exponential recovery is an oversimplification. Generally speaking, if there was an error made on the original ERD estimate, it was made on the conservative side, which is to be desired. Because of the altered radiosensitivity observed in the recovery patterns of the several species described here, the authors would be hard pressed to establish any set of hard-fast rules which would serve as a better model.

Conclusions

Because of the variability in the patterns of recovery that we have observed for multiple mammalian species, we feel that generalizations describing the recovery from radiation injury as a single component exponential are not accurate. Although exponential recovery may exist for some species, we have observed temporal alterations of radiosensitivity, e.g., initial shoulder of little or no recovery, over-recovery or radio-resistance, and increased radiosensitivity after radiation injury for other species. Therefore, we do not know which recovery pattern best describes man.

However, if a model is desired and considered to be important, we must also be ready to recognize its limitations. Thus, one must consider the possibility that man could experience temporal alterations of radio-sensitivity and that the initial shoulder of nonrecovery is a real phenomena and may extend well beyond the standard nonrecovery period of 4 days as established within the ERD concept. Furthermore, there are many factors which influence the kinetics of recovery after radiation injury. We have demonstrated here that these factors include dose rate at which the conditioning exposure is delivered, the size of the conditioning exposure, the animals specie being studied and the time after the initial radiation injury at which recovery is measured.

* Pg 87, Figure IIa: Multiplier for initial brief dose

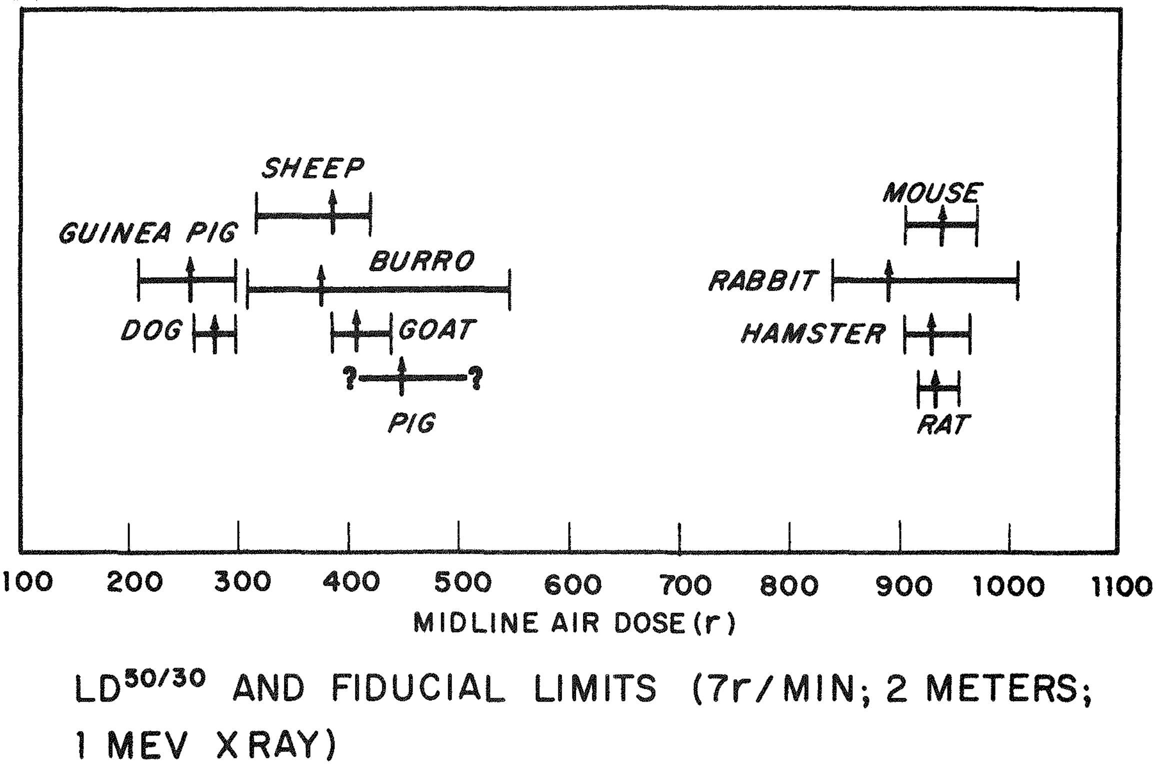


Figure 1. $LD_{50/30}$ of multiple mammal species (1 Mev X-Ray, ~7 R/min, 2 meters)

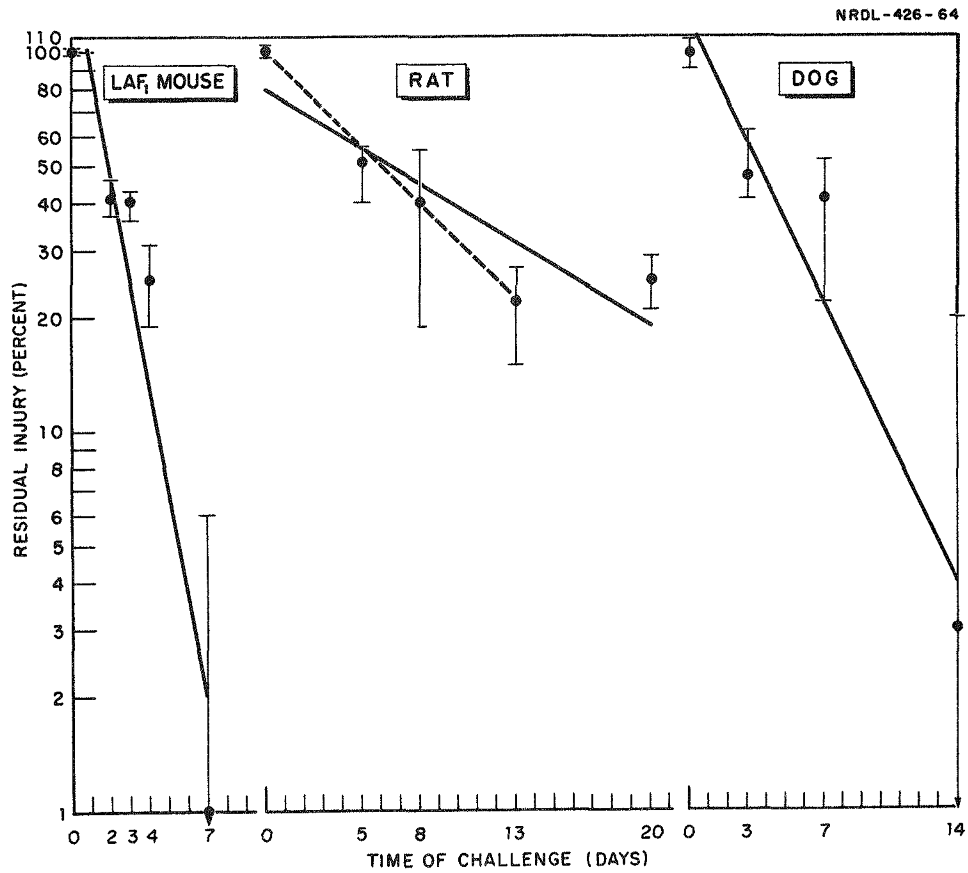


Figure 2. Recovery curves for the mouse, rat, and the dog after acute sublethal radiation exposure (2/3 LD_{50}). For the rat the dotted line is a best fit through points up to 15 days and the solid line is a best fit through points up to 20 days after the conditioning exposure.

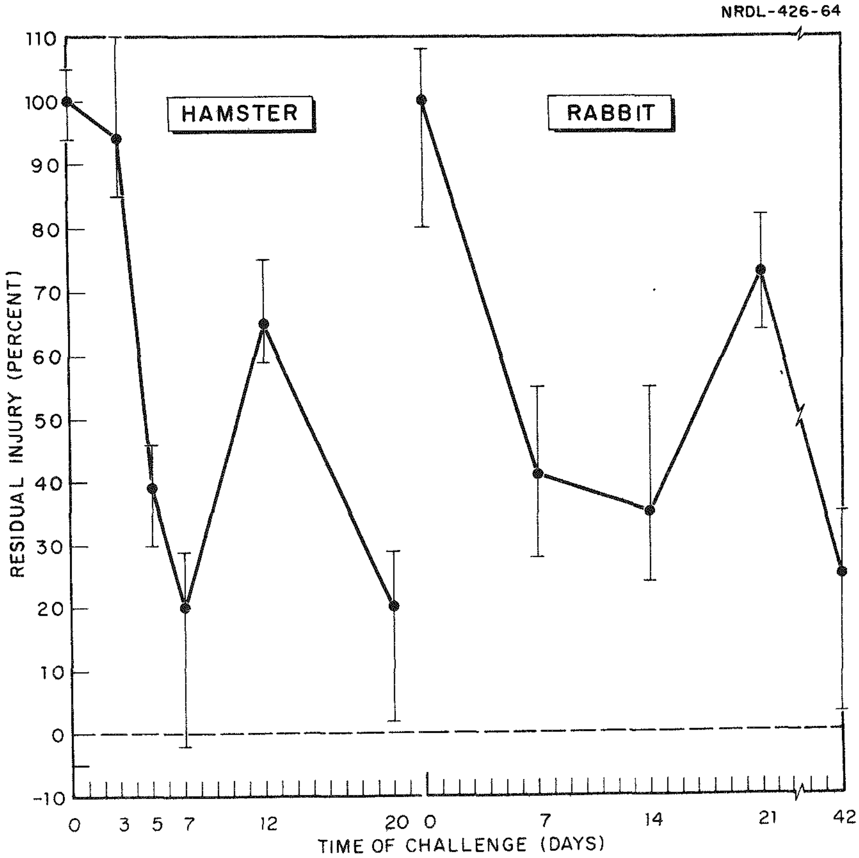
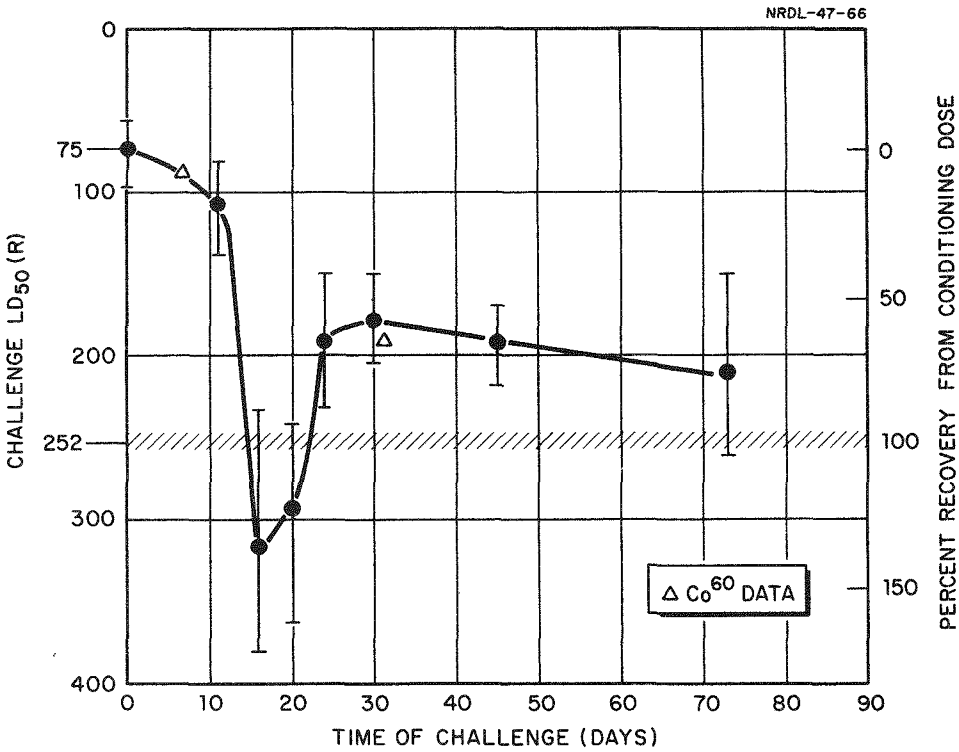


Figure 3. Recovery curves for the hamster and rabbit after acute sublethal radiation exposure (2/3 LD_{50}).



RECOVERY OF SHEEP FROM 1 MVP X IRRADIATION

Figure 4. Recovery of sheep after acute sublethal radiation exposure (2/3 LD_{50}).

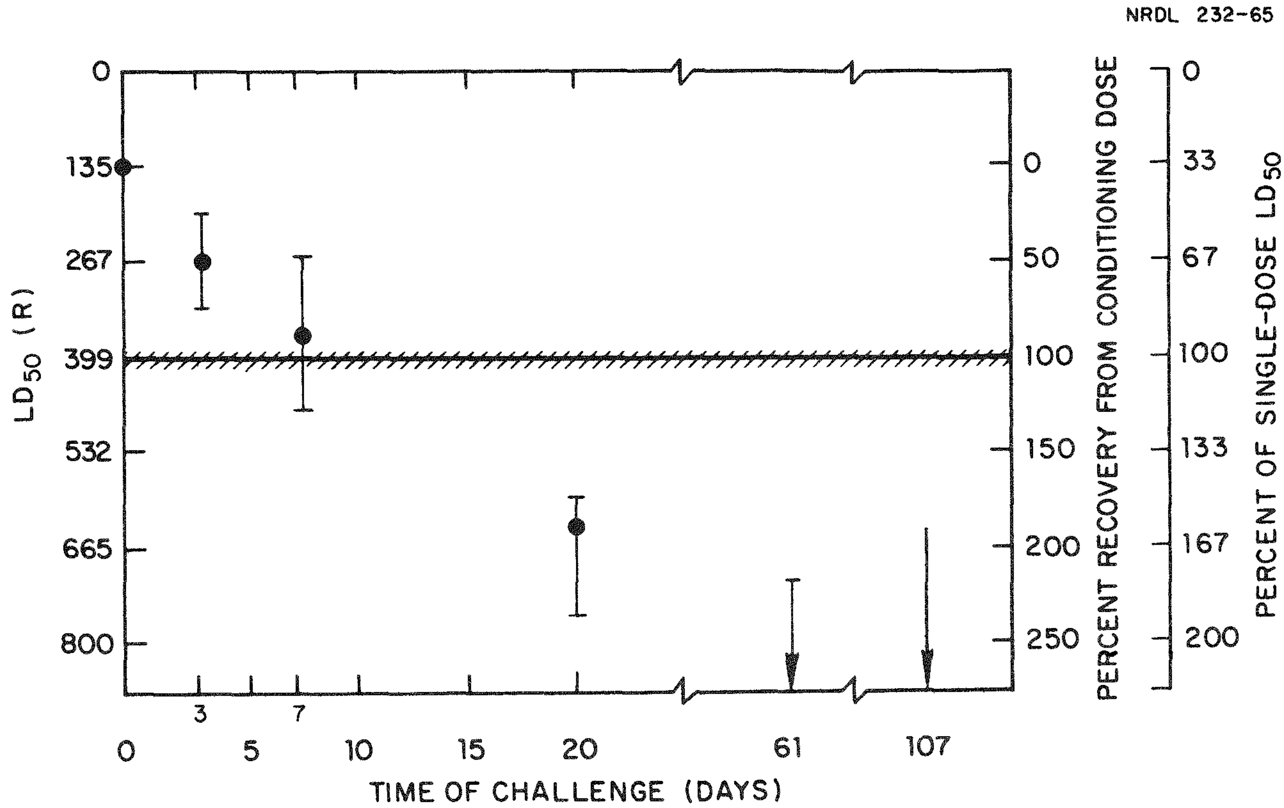


Figure 5. Recovery of swine after acute sublethal radiation exposure (2/3 LD_{50}).

INFLUENCE OF EXPOSURE RATE ON INJURY ACCUMULATION IMMEDIATELY FOLLOWING PROTRACTED Co^{60} GAMMA EXPOSURE OF 165 ROENTGENS

NRDL 516-65

DOSE RATE (R/HR) AND EXPOSURE PERIOD (DAYS)	ROENTGENS EQUIVALENT OF INJURY*	PERCENT INJURY REMAINING
0.5 — 14 DAYS	-31	-19%
0.95 — 7.5	-42	-25%
1.85 — 3.9	75	45%
3.9 — 1.75	104	63%

*CALCULATED ON REDETERMINED $LD_{50/60}$

Figure 6. Injury accumulation in sheep during protracted ^{60}Co gamma exposure (165 R).

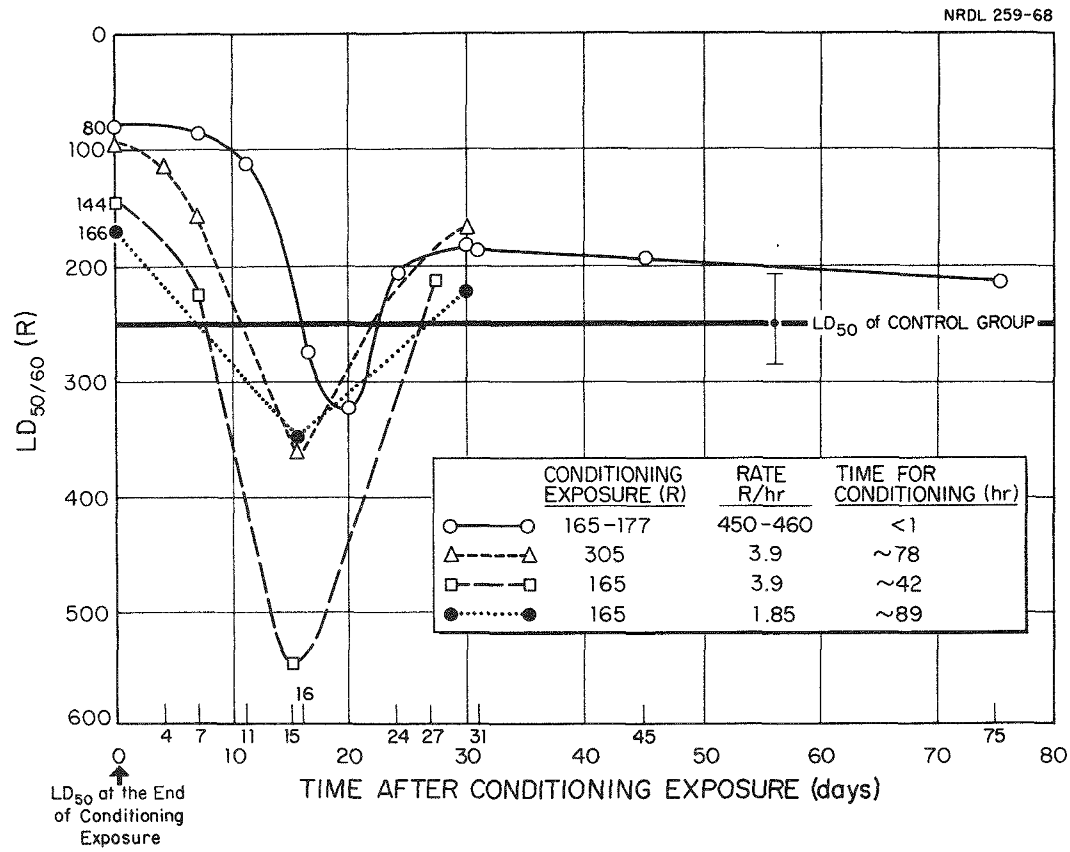


Figure 7. Recovery curves for sheep after protracted ^{60}Co gamma exposure.

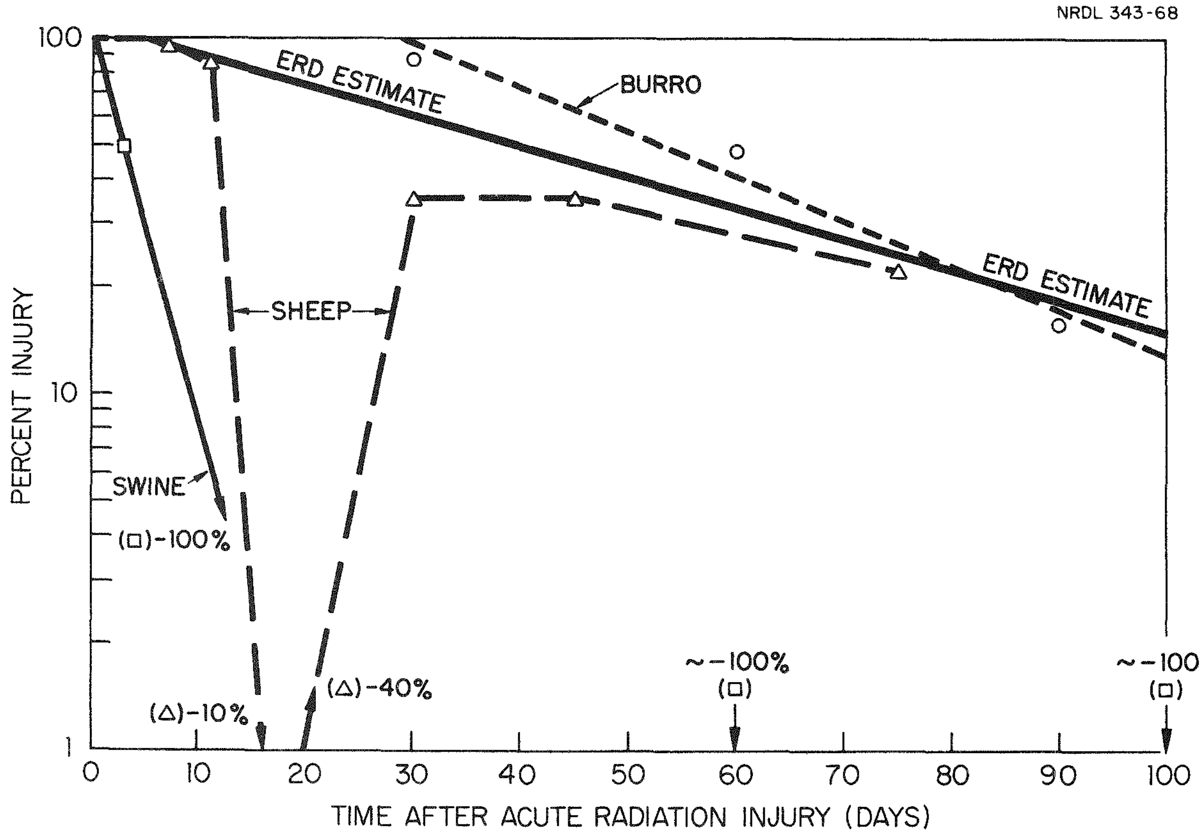


Figure 8. Comparison of ERD estimates and recovery measurements in sheep and burro.

L

PERSONNEL DOSIMETRY IN LARGE-SCALE NUCLEAR EMERGENCIES* 3.3

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ABSTRACT

Basic considerations concerning mass-scale personnel dosimetry of the civil population and/or armed forces are briefly discussed. These considerations include the general desirability of such a system, versatility and accuracy requirements, the evaluation of the dose information, the importance of dose-modifying factors, and problems of organization. It is concluded that, for tactical weapons, a photon and neutron dosimeter which measures the initial radiation is desirable. For large yield weapons, a dosimeter for the photons, and possibly also for the beta radiation from fallout may be sufficient. The main advantages and limitations of different systems which have been developed recently are compared. In particular, the use of individual or optimized combinations of luminescence (glass and TLD) systems for gamma/beta measurements, silicon diodes for neutron detection, and dose-rate independent ionometric devices (Semirad) are suitable for supplying useful information for immediate medical treatment and the estimation of possible late somatic or genetic radiation damage. Other techniques which are still under investigation may permit further improvements.

The methods and techniques used in determining the doses of the survivors of Hiroshima and Nagasaki by the ORNL Dosimetry Research Section is also briefly described. With considerable efforts, including the simulation of the actual exposure conditions using an unshielded reactor operated on a tower at up to 500 m altitude, it has been possible to determine the individual neutron and gamma doses of almost all survivors within approximately ±10%.

The need for routine personnel dosimetry for persons regularly engaged in different types of radiation work in industry, research, and medicine is now generally accepted and, in many countries prescribed by law. There has been extensive discussion about the use of personnel monitoring devices for persons possibly exposed to small radiation doses during the production and testing of nuclear explosives, their peaceful application, and during debris collection after accidental loss of nuclear weapons. The radiation exposures that occasionally occur in these cases and which are carefully measured and recorded, are rarely in a dose range in which a detectable somatic or genetic effect has to be expected. To the contrary, however, the problem of personnel exposures during large scale

* Research sponsored by the U. S. Atomic Energy Commission under contract with the Union Carbide Corporation.

by which health physicists can help to reduce the damage to be expected from such accidents.

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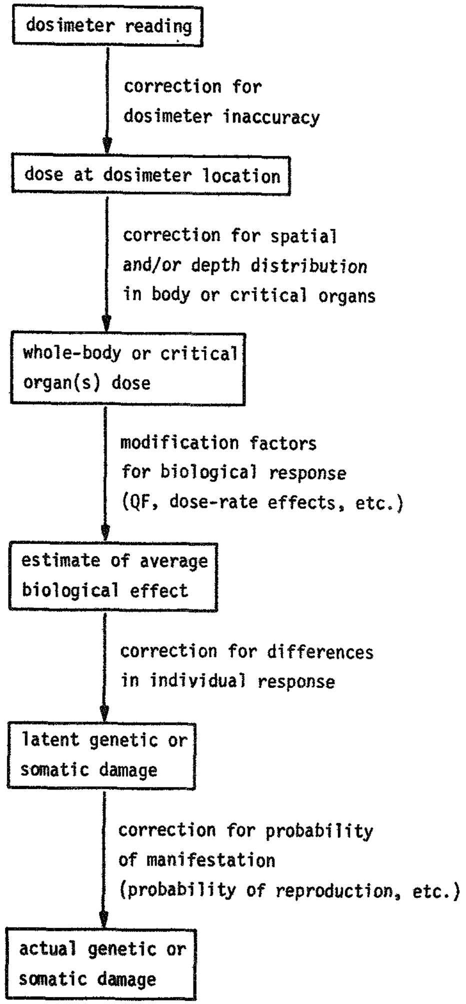


Fig. 1. Schematical diagram of the relation between a personnel dosimeter reading and the actual genetic or somatic damage to the person carrying the dosimeter.

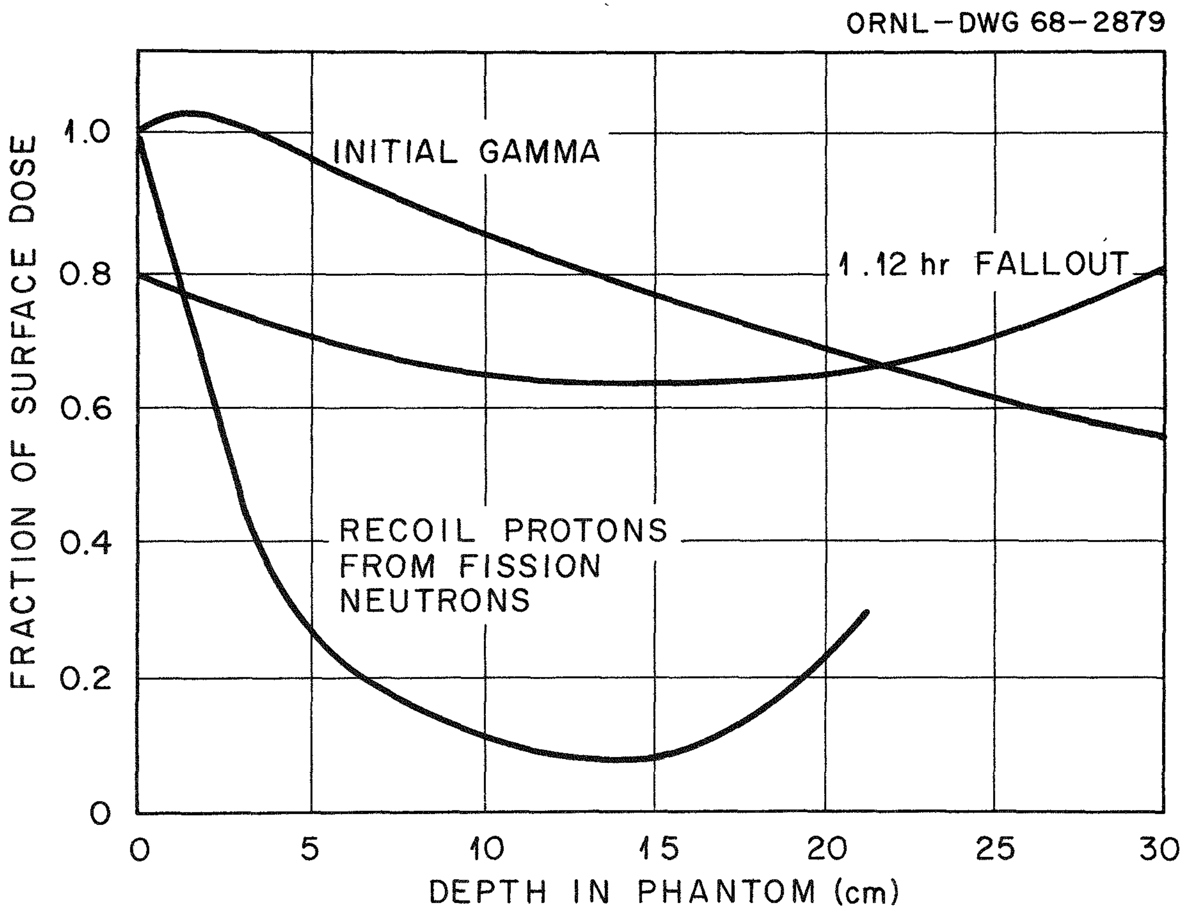


Fig. 2. Depth dose distribution in the human trunk for fresh fallout (Monte Carlo calculations)[21], initial gamma radiation,[22] and the recoil protons from fission neutrons (normalized to surface dose).[23]

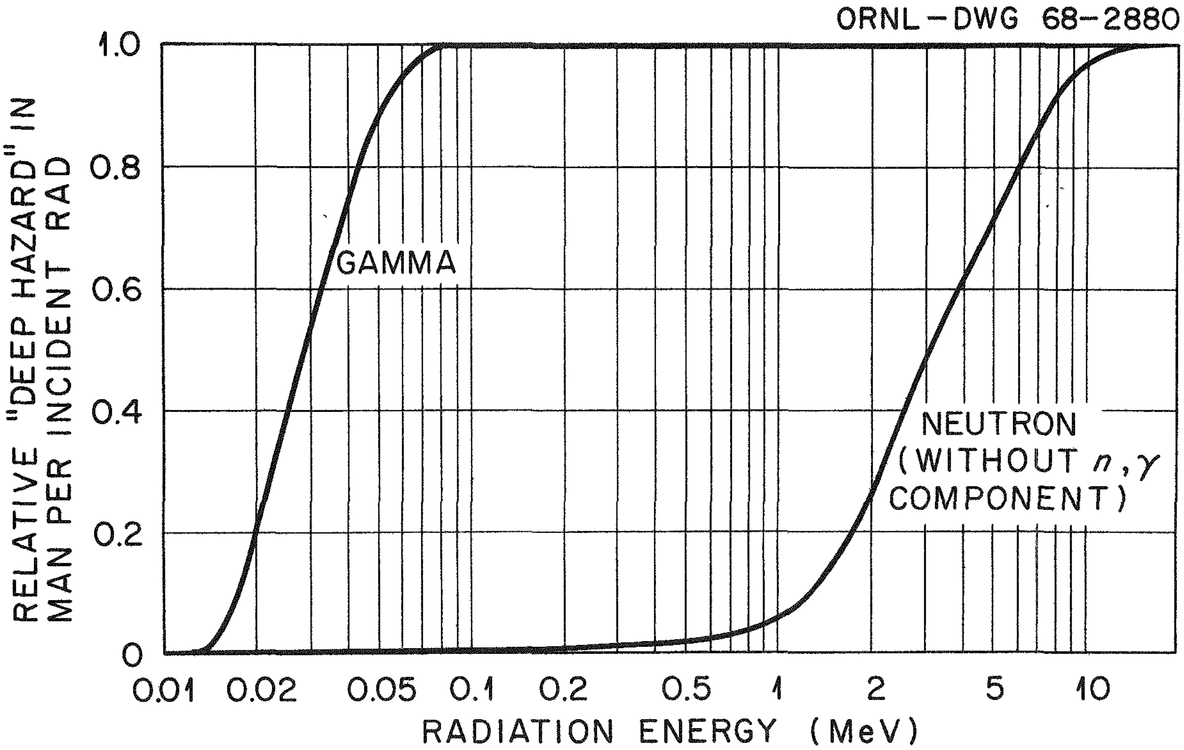
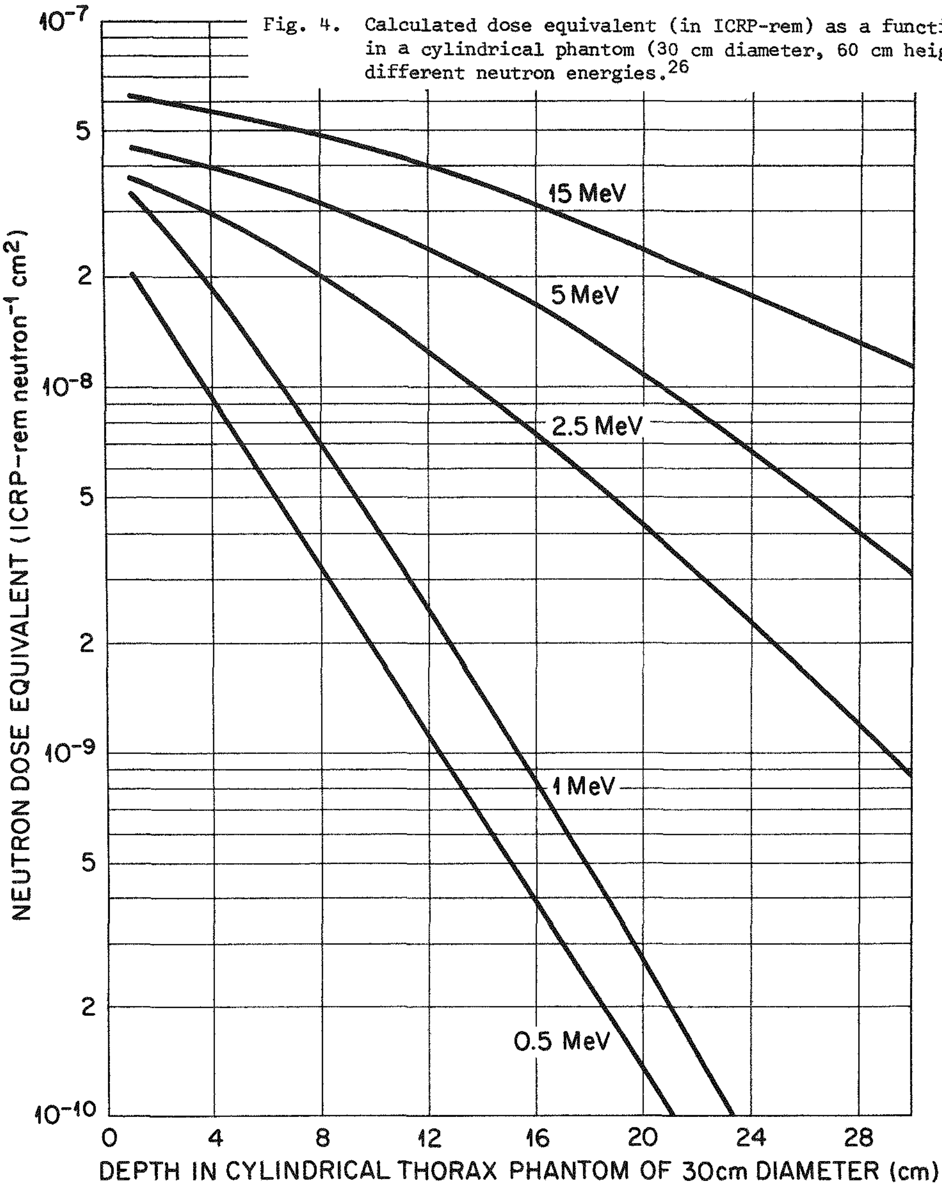


Fig. 3. Estimated relative "deep hazard" in man of neutron or gamma radiation per incident free field tissue rad as a function of radiation energy (the neutron curve excludes the (n, γ) component in the body).[2]

Fig. 4. Calculated dose equivalent (in ICRP-rem) as a function of depth in a cylindrical phantom (30 cm diameter, 60 cm height) for different neutron energies.[26]



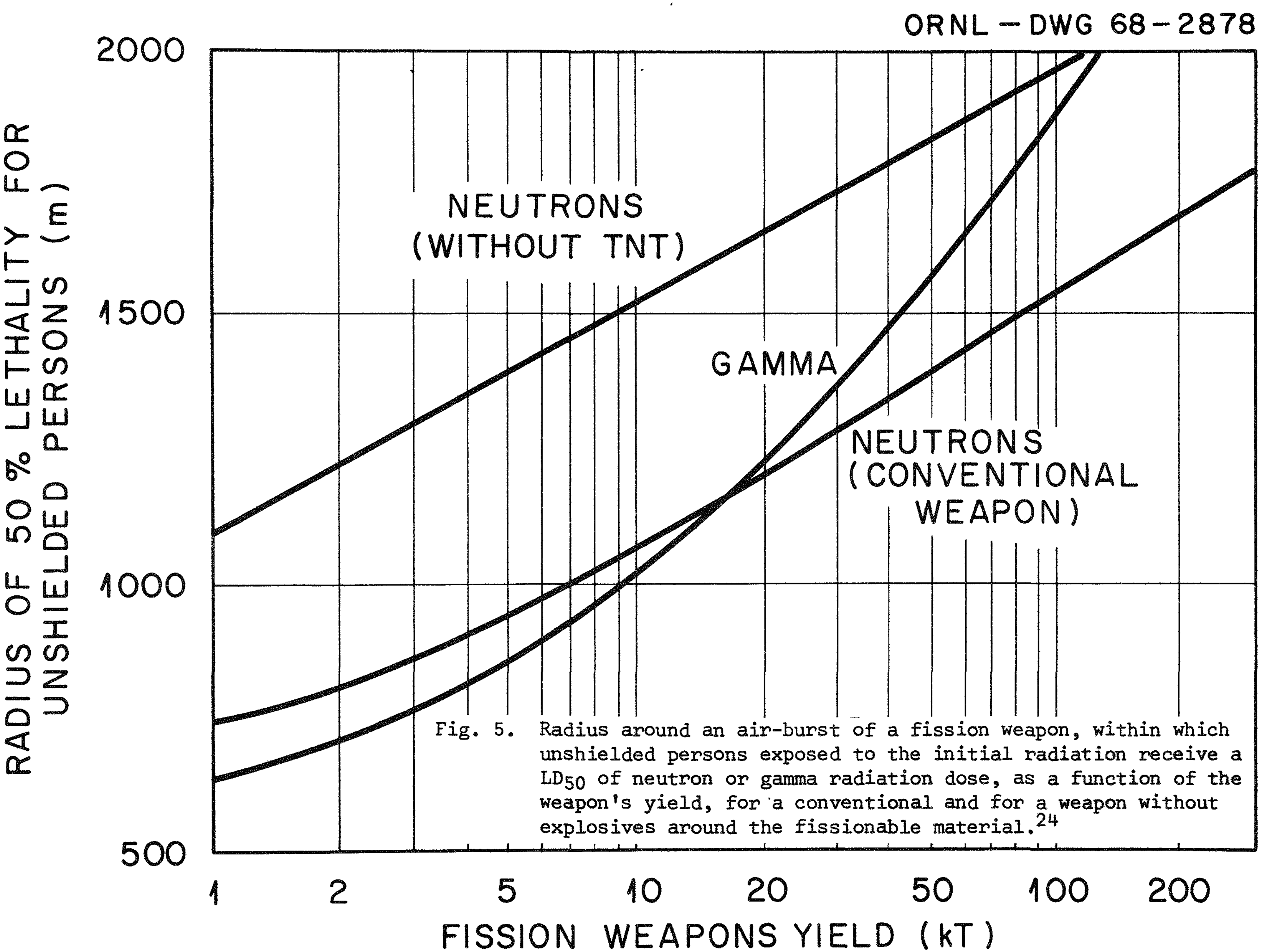


Fig. 5. Radius around an air-burst of a fission weapon, within which unshielded persons exposed to the initial radiation receive a LD_{50} of neutron or gamma radiation dose, as a function of the weapon's yield, for a conventional and for a weapon without explosives around the fissionable material.[24]

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DIETARY CONTAMINATION - ITS SIGNIFICANCE IN AN EMERGENCY 4.1

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INTRODUCTION

The problems due to the ingestion of radioactivity which might occur after nuclear catastrophes have often been discussed without regard for the external exposure which may simultaneously be received. It is not surprising that this happened when the need to consider problems of this type first arose. The evaluation of the extent to which fission products could reach man's diet, and the examination of methods whereby this might be reduced, pose problems for biologists and agricultural scientists whereas the provision of shelters to reduce external radiation requires the expertise of nuclear physicists and engineers; the two types of problem are as dissimilar as the scientific backgrounds of those whose advice was necessary. Moreover the belief, which was not always well founded, that dietary contamination would be the dominant risk to the population in all peacetime emergencies sometimes gave further encouragement to considering this mode of exposure independently of others. The inadequacy of this approach is however obvious. Because the injury which may result from exposure to radiation depends on the total radiation dose received, control measures can benefit the population only if they are directed against the major - or critical - routes of exposure. Attempts to mitigate minor sources could be of little benefit and indeed they might be positively harmful in an emergency through diverting limited resources from more useful purposes. Knowledge of the probable contribution of contaminated foodstuffs to the total radiation dose is thus essential if the control of food supplies after a nuclear disaster is to be discussed in a rational way.

Before turning to this subject it is relevant to note an important change in concepts of radiation protection which has taken place since the World Health Organization Seminar in 1963 at Geneva (World Health Organization, 1965) to which this meeting may be regarded as a sequel.

At that time limits of exposure for accidents, or "emergency maximum permissible levels", had been derived in a number of countries from maximum permissible levels devised by the International Commission on Radiological Protection for occupational exposure. The setting of such levels for individual nuclides in foodstuffs undoubtedly encouraged the view that the need to control food supplies in emergencies could be considered in isolation from other radiation risks according to arbitrary predetermined rules. The most recent recommendations of the International Commission (1966b) however explain the inappropriateness of setting rigid levels of radiation dose at which control measures should be introduced in emergencies when the source of radiation is not subject to direct control. In these circumstances the Commission now recommend that action should be guided by balancing as far as is possible the risk from radiation against the consequences - we may call it the social cost - of remedial measures. This principle is particularly relevant to the control of dietary contamination after a nuclear catastrophe as the price of restricting the use of food might well be the inadequate nutrition of the population. The importance of judging dietary contamination in a balanced and objective manner should require no emphasis.

THE CRITICAL NUCLIDES

The contamination of foodstuffs which might arise through the direct deposition of airborne material on produce after it has left the farm is excluded from this discussion as it is part of the general problem of hygiene. Questions here considered relate to foodstuffs which are being produced at the time when radioactive debris are deposited or in the subsequent period. In this context it is necessary to consider individual nuclides separately because the readiness with which they enter foodstuffs and the doses they deliver to the population depend on their half-lives and chemical characteristics; nuclides with half-lives shorter than a few hours can be ignored, except when they are daughters of longer-lived materials, because they will have largely decayed in the interval between fission and the consumption of contaminated food.

It is now well established that when mixed fission products have been released into the environment the major source of internal radiation will be due to the passage through food chains of one or other of the following nuclides: iodine-131, strontium-89, strontium-90 and caesium-137. They are the critical nuclides from the viewpoint of dietary contamination and it is impossible to envisage circumstances in which induced activities or fissile material would deserve consideration as dietary contaminants after an emergency. It is also well established that the quantity of radioactivity which can enter diet as a result of the contamination of agricultural crops is considerably greater than would be consumed in fish or drinking water from the same area; discussion can thus be confined to agricultural produce.

The basis of these generalizations has been set out in detail elsewhere (Russell, 1966) and comment in this paper is therefore confined to points which are of special relevance in the assessment of dietary contamination after emergencies or on which earlier views have recently been modified.

Iodine-131 in diet is appropriately considered primarily as a source of risk to infants. The size of the thyroid gland of an infant six months old is only about one-twelfth of that of an adult but as large, or possibly a larger, fraction of the ingested iodine may be deposited therein; moreover, milk which will often be the most contaminated food is particularly important in the diet of children.

Formerly it was often thought that infants might also receive considerably higher doses from strontium-90 than older age groups. This supposition rested on the fact that world-wide fallout led to considerably higher ratios of strontium-90 to calcium in the bones of infants than of older age groups. Recently, however, it has become evident that the much more rapid elimination of strontium from the bones of the young (Fletcher et al, 1965) largely offsets the higher initial intake. Information assembled by ICRP (1966a) on the risks from radiation suggests a further revision in assessments of risks from the isotopes of strontium. Observations on survivors of the nuclear detonations in Japan and information from other sources indicates that, when a relatively large part of the body is irradiated, leukaemia is likely to account for some half

of all fatal cancers and that bone cancers are not of high frequency among the remainder. Accordingly it is reasonable to assess risks from strontium-90 in terms of the dose received by bone marrow rather than bone itself (Federal Radiation Council, 1965; Medical Research Council, 1966). The doses from strontium-89 and strontium-90 to bone marrow are estimated to be, respectively, 0.22 and 0.26 of those received by bone (United Nations Scientific Committee on the Effects of Atomic Radiation, 1964) so that the significance of the dose from strontium-90 relative to other sources of exposure was overestimated when bone was regarded as the critical organ. In subsequent discussion an additional reason will be given why the doses received from strontium-90 over long periods were formerly overestimated; it is now evident that this nuclide enters plants less readily from the soil than the early assessments suggested.

Evidence that caesium-137, like strontium-90, is retained for a much shorter period in the bodies of infants than of adults has now been obtained in a number of studies (McCraw, 1965; Rundo and Taylor, 1964). Recent calculations show that the radiation dose delivered by unit intake of caesium-137 differs by only small factors between different age groups because the smaller body size of children is largely offset by their more rapid elimination of the nuclide, though they still receive somewhat higher doses.

Relationships between the intake of the critical nuclides and doses to the population used in this discussion are set out in an Appendix.

TRANSFER OF FINELY DIVIDED, FREELY SOLUBLE FISSION PRODUCTS THROUGH FOOD CHAINS

Quantitative information on the transfer of fission products into foodstuffs comes mainly from experiments in which separated fission products have been used or from observations of world-wide fallout. Both sources of information relate to the behaviour of freely soluble and finely divided deposits. It will be shown later that the physical form of debris which would descend in highly contaminated areas after nuclear catastrophes would greatly modify its transfer to foodstuffs but none the less the behaviour of finely divided, freely soluble deposits provides important background information.

Shortly after mixed fission products have been released, iodine-131 and strontium-89 are present in much higher activities than the two long-lived nuclides. Depending on the mode of fission the relative abundance of the nuclides shows some variation but the figures in Table 1 are adequately representative for present purposes; it can be readily calculated from the dose relationships given in the Appendix that in the early period after mixed fission products have been deposited in fission yield, doses from strontium-90 and caesium-137 would be trivial by comparison with those from iodine-131 and strontium-89. If the debris are deposited in fission yield the long-lived nuclides could become the critical nuclides only after iodine-131 and strontium-89 had decayed. Except when other references are given the sources on which subsequent discussion is based are cited by Russell (1966).

The early period: Provided that fission products are deposited during the summer, milk is the foodstuff which would be most extensively and rapidly contaminated with both iodine-131 and strontium-89. Not only are the two nuclides readily transferred to milk but finely divided debris are efficiently entrapped on the pastures which animals graze. The results of numerous experiments suggest that perhaps 25% of the finely divided deposit may be retained initially on the edible foliage of pastures, and when it is borne in mind that a dairy cow may consume the produce of from 50 to over 100 m^2 of pasture per day the efficiency with which it can scavenge the deposit is evident. After deposition has ceased, radioactivity in herbage will decrease not only through removal by cattle and the decay of radioactivity, but also as a result of leaching in rain, the dislodgement of particles by wind and dilution by new growth. Studies both in the United Kingdom and in the United States suggests that this "field loss" will reduce the contamination of herbage by a factor of about 2 every two weeks. In Table 2 estimates are shown of the concentration of fission products in milk which would be expected if cattle were deriving their entire diet from pastures of average productivity (cir. 50 g edible dry matter/m^2); caesium-137 has been included in Table 2 despite the fact that it will be a trivial source of radiation relative to iodine-131 or strontium-89 when mixed fission products are deposited as it may be of greater significance in other circumstances. Although the values shown in Table 2 represent the mean results of a large number of investigations it is important

to emphasise that variable environmental factors can cause large variations; the results in the Table are shown to two significant figures because rounding would increase error when they are used in subsequent calculation. Table 2 relates to the situation during the summer months when animals may be deriving their entire diet from grazing; an appreciable quantity of supplementary food is frequently provided and lower levels of contamination would then be expected. Indeed if a disaster were to occur in winter, when cattle are fed on stored food in barns, the contamination of milk would be trivial. Thus, despite uncertainties Table 2 may be regarded as a conservative basis for assessment. During the early period foods other than milk would convey much less radioactivity into diet and for present purposes they can be ignored.

The long-term situation: As time passes after the deposition of fission products strontium-90 will enter all articles of diet in varying degrees, none the less for the present purpose it is adequate to consider only the contamination of milk. This is because the ratio of strontium-90 to calcium in milk, integrated over an extended period, differs little from that in a complete diet of the general type normally consumed in Western countries (Bruce et al, 1966); milk thus serves as a convenient index of the total contamination of foodstuffs. The most extensive data on the relationships between the deposition of strontium-90 on agricultural land and the levels of that nuclide in milk come from surveys of world-wide fallout. On a simple analysis, the strontium-90 present in milk at any one time can be regarded as consisting of three components:-

The rate component - This results from the entrapment of the recent deposit on pastures which cattle are currently grazing.

The lag-rate component - This takes account of the fact that animals normally derive an appreciable part of their diet from food which was grown in the previous year and therefore entrapped fallout deposited at that time; furthermore under some circumstances this component will be in part due to the retention of strontium-90 for appreciable periods in the basal tissues of plants from which it can be absorbed more readily than from the soil.

The soil component - This is due to absorption from the total deposit retained in the soil.

In assessing relationships between the deposition of strontium-90 and the extent of dietary contamination the average annual levels are usually considered and in the United Kingdom the following equation has been adopted:-

$$C = p_r F_r + p_l F_l + p_d F_d$$

where C is the annual mean ratio of strontium-90 to calcium (pCi/g) in milk; F_r is the annual deposit (mCi/km^2/year); F_l is the deposit in the second half of the previous year (mCi/km^2); F_d is the cumulative deposit (mCi/km^2) and p_r, p_l, p_d are described as the "rate", "lag-rate" and "soil" proportionality factors, respectively (Bartlett and Russell, 1966).

This equation should be regarded as only an approximate description of the processes which control the transfer of strontium-90 to milk. It is known for example that the soil factor is not strictly constant with time but will decrease slowly because of the downward penetration of strontium-90 in the soil; moreover the "lag-rate" factor relates to an arbitrary period. When however the proportionality factors are derived by least squares analysis from the results of the extensive environmental surveys which have been in progress in the United Kingdom since 1958 the calculated values for each year are within 7 per cent of those actually observed. The procedure thus seems adequate for present purposes. The values of the proportionality factors are: Rate factor: 0.70; Lag-rate factor: 1.13; Soil factor: 0.11 (Bartlett, 1967).

In earlier calculations when less extensive data were available no account could be taken of the lag-rate factor and a two term equation was therefore used; this gave a significantly poorer fit to the data, the soil factor being appreciably higher (Bartlett and Russell, 1966). Independent evidence that the value derived by the three term equation describes the situation more correctly is provided by the fact that tracer experiments in which radioactive strontium was incorporated in the upper 10-12 cm of soil gave broadly similar results; moreover in late 1967 when the rate of fallout was very low, so that contamination of milk could be attributed predominantly to uptake from the soil, a similar value of the soil factor was obtained assuming that the observed level in milk was due solely to the cumulative deposit.

Since climate and agricultural conditions affect the transfer of strontium-90 into diet it cannot be expected that relationships observed in any one country will precisely describe the situation in others. However, results of surveys of dietary contamination with world-wide fallout for the majority of European countries fall within a fairly narrow range (UNSCEAR, 1966). Thus in the absence of equally extensive information from other areas the United Kingdom findings are used in the present discussion.

Quantitative relationships for the transfer of caesium-137 into foodstuffs are less well known than those for strontium-90. The ability to measure body burdens of caesium-137 in living subjects with whole-body counters makes it easier to relate current tissue levels of this nuclide directly to the measured deposit in the environment than is possible with strontium-90. Detailed information on the transfer of caesium-137 is thus of less importance. The most important ways in which the behaviour of caesium-137 in food chains contrast with that of strontium-90 is with respect to uptake from the soil. Unlike strontium-90, caesium-137 is readily entrapped in the lattice structure of clay minerals. This renders it largely inaccessible to plants; thus dietary contamination with this nuclide is mainly determined by the recent deposit. Some soil types are known from which caesium-137 enters plants as readily as strontium-90 but they are rare in densely populated temperate areas and need not concern us here.

Radiation doses from world-wide fallout: Although the effects of world-wide fallout are outside the scope of this paper, the relative magnitudes of the doses received from different components are of interest since world-wide fallout is on average deposited in fission yield and in a soluble form.

Radiation doses from those components of world-wide fallout which are relatively uniformly spread over the entire population are commonly expressed in terms of the dose commitment, which may be defined as the radiation dose integrated over time to any type of tissue. Table 3 shows estimates of the dose commitment to the year 2000 to which the population of the United Kingdom might be exposed as a result of weapons testing until 1966; since then the situation has not changed materially. Estimates of the dose commitment to the entire world population are subject to greater quantitative uncertainty than those

for a single country where surveys are carried out on an appreciable scale but none the less, world-wide estimates made by UNSCEAR (1966) do not differ greatly from the United Kingdom assessment. Doses from iodine-131 are not included in Table 3 since, as already explained, these are received predominantly by the very young especially if they consume fresh milk. Moreover exposure occurs only for short periods when tropospheric fallout is considerable. It is estimated, however, that in each of the years 1960 and 1961, when fresh fallout was relatively high, infants in the United Kingdom and in other countries of similar latitude in the northern hemisphere might have received annual thyroid doses of about 0.1 rad. Table 3 shows that no other component of world-wide fallout delivered doses of similar magnitude. Considerably higher doses from iodine-131 were experienced at sites close to weapon proving grounds on the American mainland which were on some occasions subject to exceptional tropospheric fallout (Dunning, 1958; Knapp, 1963). The reason for this is evident from the composition of mixed fission products (Table 1) and the relationship between the deposition of individual nuclides and tissue doses shown in the Appendix.

Finally, with regard to world-wide fallout it is relevant to note the comparisons between doses received from this source and natural background which are shown at the foot of Table 3. It is evident that fallout from past nuclear weapons has caused a much smaller increase in the total radiation environment of the population than has sometimes been imagined.

INDUSTRIAL EMERGENCIES

Before considering dietary contamination after catastrophes it is relevant to refer briefly to the types of situation which might occur after industrial emergencies. When the study of food chains first received consideration the possible consequences of reactor accidents were frequently considered a major reason for the investigation of this question. One of the most comprehensive reviews yet made of risks from nuclear reactors was presented by Farmer (1967) at a symposium of the International Atomic Energy Agency; an appendix to this paper by Beattie discussed the effects of iodine-131 and a considerably more detailed discussion of this and other hazards has been provided earlier by the same author (Beattie, 1963).

The extent to which different fission products could escape after a disaster to a nuclear establishment would largely depend on their volatility and for this reason iodine-131 would be of dominant concern. This was well illustrated after the accident at Windscale Works in 1957 when, relative to the content of the reactor, that nuclide was released about 100 times as readily as strontium-89 (Chamberlain and Dunster, 1958). If the most pessimistic assumptions are made, for example, that iodine-131 is released at a relatively low altitude in an inhabited area it can be concluded that the limiting risk, during the early period, would be inhalation by persons living within 1-2 km of the establishment. However, as Farmer and Beattie have shown, the average risk to persons permanently resident in such areas should be smaller by several orders of magnitude than risks of other kinds to which they are exposed and which they normally ignore; this assessment, of course, presupposes that the safety standards in nuclear establishments continue to be maintained at their present high level.

If a reactor accident occurred at a time of year when cattle were grazing on pastures the entry of iodine-131 into milk could create a problem in the surrounding area. This was the situation experienced after the accident at Windscale Works in 1957. The quantity of iodine-131 then released was estimated at 20,000 Ci (Loutit et al, 1960) and the assessment of Farmer suggests that safeguards in modern nuclear establishments should be such that a release of this magnitude should occur with a frequency of less than once in 10,000 years. Bearing in mind that the probable life of a nuclear reactor may be about 30 years such an event is so unlikely that it would be ignored in other contexts. The possible consequences of such a release of iodine-131 are indicated by events after the Windscale accident which occurred when cattle were on pasture. The distribution of milk was restricted to prevent any infant receiving a dose to the thyroid of more than 25 rads; on the basis of the assessments of ICRP (1966a) this radiation dose portends a risk of cancer to the thyroid of less than 1 case in 1000. The total area affected by the milk restrictions was about 500 km^2. However, it now appears that the desired degree of control could have been obtained by restricting milk supply over less than half this area; this is because the information then available on the transfer of iodine-131 to the thyroid glands of infants and on the retention of that nuclide on pastures have been shown by more recent data to be overcautious.

It may be concluded therefore that any releases of iodine-131 which may reasonably be expected to occur even after the gravest industrial disaster could cause only local agricultural problems.

The quantities of caesium-137, strontium-89 and strontium-90 released after the Windscale accident were so small relative to those of iodine-131 that they gave rise to no problem. It is of interest, however, to note the approximate order of magnitude of the doses to which they might have given rise in the absence of control measures. It was estimated that about 600 Ci of caesium-137 escaped into the environment or 3 per cent of the activity of iodine-131; the corresponding figure for strontium-89 was about 0.5 per cent (Loutit et al, 1960). The Appendix to this paper shows the relative magnitudes of doses expected from the three nuclides when equal activities are deposited and the data provided by Loutit et al (loc cit) enable the maximum dose from iodine-131 which would have been experienced in the absence of control measures after the accident to be inferred. On this basis it appears that no milk produced at that time would have delivered as much as 0.3 rad from caesium-137, the dose from strontium-89 being considerably smaller.

Because of the attention which has been given to strontium-90 as a source of continuing concern it is of interest to consider the release of this nuclide from this viewpoint. Whereas the incorporation of 45 Ci/km^2 in soil would cause the bone marrow to receive 1 rad/year through the ingestion of contaminated milk (see Appendix), the total release in the accident was 2 Ci (Loutit et al, 1960). Thus if the total quantity of strontium-90 which escaped had been confined to 1 km^2 of ground surface instead of becoming widely dispersed it would have given rise to doses to the bone marrow of only about 0.05 rad/year, that is to say about half the natural background dose. The most contaminated milk observed showed a considerably lower level of contamination with strontium-90 (Ellis et al, 1960). It is evident therefore that the releases of fission products other than iodine were smaller by very considerable factors than those which would have given rise to appreciable dietary contamination. Bearing in mind the scale of the accident it may be concluded that iodine-131 alone deserves consideration as a source of dietary contamination in such circumstances.

NUCLEAR CATASTROPHES

The situation in a fallout field, caused by a single nuclear weapon, in which the deposit would cause an external gamma dose of 100 R/hour 1 m above ground surface at 1 hour, provides a suitable basis for judging the contribution of dietary contamination to the total radiation dose received by the population after a nuclear catastrophe. This level of fallout could occur several hundred miles down wind after a megaton explosion (Glasstone, 1962) so that, in thermonuclear warfare, it would be regarded as relatively mild contamination. None the less, it is an appropriate model for the present discussion since:-

(i) Especially if fallout did not arrive until 12-24 hours after the detonation, relative light sheltering could cause casualties due to external radiation to be low so that the recovery of agricultural produce might soon be practicable.

(ii) In physical and chemical characteristics the deposit in these areas would be sufficiently similar to those at more heavily contaminated regions for the relationship between internal and external radiation to be reasonably representative of situations nearer to ground zero.

The wide variation in the character of the deposit which can occur depending on the circumstances of a nuclear detonation make it unrealistic to attempt more than a very approximate assessment of the internal radiation doses which might be sustained. On balance it could reasonably be argued that the contribution of dietary contamination to the total radiation dose will usually be lower than is suggested in subsequent discussion. Conditions relatively favourable to the transfer of radioactivity through food chains have been assumed and, moreover, no account has been taken of the appreciable additional external dose which would frequently arise from induced activities. This biased presentation is intentional; there is strong evidence that dietary contamination would be responsible for a much smaller fraction of the total radiation dose than has frequently been imagined, and the correction of this misunderstanding would not be aided by calculations which err in the opposite direction.

The situation in areas subjected to heavy near-in fallout would contrast with that caused by world-wide fallout in two principal respects:-

(i) Deposition would occur within a few hours of fission

and (ii) The physical form of the deposit would greatly modify the availability of the critical nuclides for transfer through food chains.

Since the total activity of fission products decreases by a factor of approximately 10 for every 7 units of time after fission, and the mean age of the fission products deposited as world-wide fallout is a year or more, it is evident from Table 3 that when fresh fission products are deposited, external radiation from short-lived activities will exceed internal radiation due to long-lived nuclides by a very considerable factor. Furthermore, in view of the doses received by infants from iodine-131 relative to other internal doses from other nuclides (see page 9), it is evident that this nuclide would be the dominant source of dietary contamination after a nuclear catastrophe. These conclusions are considerably reinforced when account is taken of the composition and physical form of fallout.

Relationship between the external gamma dose from fission products and the deposit of the critical nuclides: Dunning and Hilcken (1956) have estimated that the deposition of 800 MCi mixed fission products per square mile 1 hour after fission would give an external gamma dose rate of 4000 R/hour at three feet above a theoretically flat plane. Assuming that the roughness of the ground would attenuate the external radiation dose by a factor of two, that the contribution of the critical nuclides to the total fallout activity is that shown in Table 1, that mixed fission products are deposited in fission yield and that they decay by a factor of about 36 between 1 and 24 hours, the expected quantity of the critical nuclides in a deposit of mixed fission products which delivers 100 R/hour at 1 hour after fission can be calculated; the resultant values are shown in Table 4, column 2. An alternative calculation based on more recent information provided by Glasstone (1962) suggests that the deposit may be only about one-third of that shown in Table 4 but the higher value is here used having in mind possible variability in different circumstances.

The figures in Table 4, column 2, assume deposition in fission yield, and account must be taken of fractionation which causes volatile nuclides, or those which have volatile precursors, to be depleted in near-in fallout. Krypton-89 and krypton-90, the precursors of strontium-89 and strontium-90 respectively, thus lead to the depletion of these nuclides; xenon-137 has the same effect on caesium-137, while iodine-131 is itself volatile. Estimates of the magnitude of fractionation vary widely; those shown in Table 4, column 3 have been selected as conservative on the basis of the evidence of Dunning (1959), Edvarson _et al_ (1959), Frieling (1961), Loutit and Russell (1961) and Triffet (1959). The estimated deposit of the critical nuclides in fractionated fission products which give rise to 100 R/hour at 1 hour can be obtained by dividing the values for unfractionated fission products by the fractionation factor (Table 4, column 4).

Physical form of the deposit: Two physical attributes of fallout are of considerable importance in determining the extent to which radioactivity will enter food chains, namely, particle size and solubility. Depending on the condition of an explosion, the particle size of the deposit may vary appreciably, but it is well recognized that the average dimensions of the near-in debris will be considerably greater than that at remote sites (Loutit and Russell, 1961; Schuert, 1957; Triffet, 1959). The figures shown in Table 5 serve as a general guide to situations, down-wind from ground zero, at which the external gamma dose rate at 1 hour is in the ranges shown. In the present discussion the size of fallout particles is principally of importance because of its effect on the retention of debris on vegetation which grazing animals or man may eat. Whereas experimental studies (see page 5) show that up to about a quarter of finely divided deposit may be retained on the edible tissues of pasture, it is well established that debris of appreciable particle size will largely rebound from leaf surfaces. This inverse relationship between particle size and retention of foliage was first recognized by Larsen and his co-workers (see Romney _et al_, 1963) who examined the native vegetation at a United States weapons proving ground. Since such sites are located far from agricultural areas it is not surprising that there are few quantitative data on the retention of particulate fallout by pastures. We are forced to rely mainly on experiments carried out at weapons trials in Australia (Loutit and Russell, 1961) in which boxes containing grass clipped to resemble temperate pastures were exposed at various distances from ground

zero. The herbage was cut a few hours after the detonation with the objective of collecting material comparable to that which animals would ingest on the first day. When particle size was relatively small 15 per cent or more of the deposit was retained on edible tissues, a result comparable to that found in other studies of finely divided deposits. However, only 1-2 per cent of the deposit was retained on edible tissues where fine particles (e.g. less than about 5 μ) accounted for only a very small fraction of the total deposit. Autoradiographs provide a clear explanation of this situation; the large particles mainly lodged in the basal tissues which animals reject. Especially when it is borne in mind that the grazing animal causes considerable disturbance to the grass during grazing, further dislodgement of particles is likely. None the less the upper range of the observed values are used in Table 5.

There is much evidence that near-in particulate debris is of relatively low solubility (Nishita and Larson, 1957; Lindsten et al, 1961; Loutit and Russell, 1961; Triffet, 1959). There have been some suggestions (Hollister, 1963; Miller, 1963) that iodine-131 may be more soluble than other fission products, but this is not supported in a number of studies reviewed by Holland (1963). As solubility may vary widely, depending on the circumstances of a detonation, the upper range of recorded values has been used in the present assessment (Table 5).

Since the only quantitative information now available, from direct measurement, on the transfer of fission products into foodstuffs relates to finely divided freely soluble deposits, it is necessary to consider the manner in which such estimates must be modified to take account of the physical form of near-in fallout. In the early period when the direct contamination of growing plants will be the primary source of dietary contamination the combined effect of particle size and low solubility must be considered; it appears that in areas of medium or heavy fallout, the transfer of the debris through food chains would be reduced by a factor of about 100 relative to a finely divided freely soluble deposit (Table 5, column 5). The entry of strontium-90 into crops from the soil in subsequent years will however be affected only by solubility; thus in areas of heavy deposits only a tenfold reduction in the transfer of this nuclide is to be expected.

Expected internal doses in a fallout field of 100 R/hour at 1 hour caused by a single nuclear weapon: The internal doses expected in consequence of dietary contamination can be calculated from the estimated deposit of the critical nuclides (Table 4), the physical characteristics of the deposit (Table 5) and the relationships shown in the Appendix to this paper. The resultant estimates are shown in Table 6; they may be compared with the total external dose of over 400 R which would be experienced, in the absence of shelters, if fallout arrived at 1 hour after the detonation or about 200 R if it arrived at 24 hours.

Iodine-131 is the only source of ingested radiation expected to deliver doses comparable in magnitude with the external dose from fission products. Especially if several hours elapsed before fallout descended the provision of even relatively light protection against external radiation would cause iodine-131 to be the dominant source of radiation to children. In contrast, doses from strontium-89 and caesium-137 in the early period, or strontium-90 which enters diet from soil in the subsequent years, would be similar to or smaller than the normal natural background.

Furthermore, in considering the situation in future years account must be taken of the massive world-wide fallout which any nuclear war would bring in its train. Some basis for gauging is provided by considering the possible consequence of 1000 megatons of fission; vastly greater fission has been assumed in many civil defence assessments. It has been estimated (UNSCEAR, 1964) that 100 megatons of fission products were released by weapons tests in 1962 and 1963 and this caused some 20 pCi ^{90}Sr/g Ca to reach milk as a result of the direct contamination of herbage in the two subsequent years (Bartlett and Russell, 1966). It may therefore be assumed that 1000 megatons of fission would give rise to about 200 pCi ^{90}Sr/g Ca in milk for a period of about two years, with appreciably lower levels subsequently. From the Appendix to this paper it can be estimated that the dose rate from strontium-90 in the early years of world-wide fallout would be about 0.05 rad/year. Taking account of the contribution of other components of world-wide fallout (see Table 3) and the likelihood that considerably more than 1000 megatons of fission would occur, it is evident that world-wide fallout and not the contamination of foodstuffs with the residual deposit in the soil could present the main problem of future years.

Table 5 shows that the magnitude of internal doses due to dietary contamination in the early period would be greater, relative to the external dose, if a deposit equivalent to 100 R/hour at 1 hour were due to several overlapping weapon plumes. The significance of iodine-131 would then be enhanced. However, having in mind the much lower doses from the other nuclides shown in Table 6, there are no grounds for imagining that they would make major contributions to the total exposure by the population.

Expected internal doses at distant sites: Table 5 shows that fission products are much more "available" for transfer through food chains in relatively lightly contaminated areas; for example, the fraction of the deposit which enters diet is expected to be 50 times greater in a fallout field equivalent to 0.1 R/hour at 1 hour than in one of 100 R/hour. Thus dietary contamination will contribute a much larger fraction of the total radiation dose at distant sites. Iodine-131 would remain the nuclide of dominant concern and its effects could be experienced at great distances. The doses to infant thyroids due to past world-wide fallout and the estimated weapon yields referred to earlier in this paper suggest that the thyroids of infants fed on fresh milk, throughout the entire latitudinal belt on which weapons are detonated, might on average receive about 2 rad for every 1000 megatons of fission. This calculation assumes that contamination occurs when cattle are grazing; the conditions of detonation, meteorological factors and distance from the site of detonation would cause great variability.

CONCLUSIONS

Even when account is taken of the uncertainties inescapable in present assessments it appears that in nuclear catastrophes iodine-131 would be the only fission product which would deserve serious consideration as a source of dietary contamination.

After the detonation of nuclear weapons the fraction of the total radiation dose for which iodine-131 is responsible would be considerably greater in areas of relatively low contamination than at near-in sites where external radiation would be dominant. Strontium-90 can continue to enter diet to some extent for many years after its deposition but, if significant problems were caused by external radiation in the early

period, the residual strontium-90 in the soil would often contribute but a small dose to the population relative to that which would be inescapable from the world-wide fallout consequent on many thousand megatons of fission. There seems little profit in considering remedial action against the continuing deposition of strontium-90 or caesium-137 in world-wide fallout since doses from these nuclides could not be reduced by a significant factor without disrupting the entire food supplies of the population.

Accordingly it seems reasonable to limit civil defence plans with regard to radioactivity in food to the control of iodine-131. The designing of measures to reduce the exposure of infants from internal radiation from this nuclide in milk would present simple problems in a community if its resources had not been seriously disrupted. For example, the drying of milk or its manufacture into butter, cheese or other products, combined with storage for a few months, could make the produce acceptable; plans for special decontamination facilities seem unnecessary, nor need the destruction of food supplies because of their burden of radioactivity be considered. The provision of stable iodine to block the transfer of iodine-131 to the thyroid should also be considered.

Unfortunately the recognition that dietary contamination would cause smaller problems than have sometimes been imagined does not imply that the total consequences in nuclear warfare has been in any way overestimated. Rather the reverse. The catastrophic consequences to which external radiation could give rise require no emphasis. Furthermore, in the recovery period after a nuclear holocaust, dietary contamination from world-wide fallout could place a considerable and largely uncontrollable burden on the population.

New information however justifies much greater optimism with regard to dietary problems after accidents which might occur in peacetime. Five years ago at the World Health Organization Symposium (WHO, 1965) some contributors envisaged accidents which might create international problems and it was suggested that special measures might be necessary to rehabilitate farm lands on which long-lived nuclides had been deposited. The assessment of the consequences of accidents, to which reference has been made in this paper, and information on the

transfer of fission products through food chains now shows that even the largest - and highly improbable - accident would create only local, as opposed to national, problems. Iodine-131 would again be the nuclide of concern from the viewpoint of dietary contamination; the presence of long-lived fission products in soil is most unlikely ever to cause significant dietary contamination. When less information was available it was prudent to take account of the most gloomy possibilities but it is equally desirable that such views should be corrected when new information becomes available. Otherwise the community might be discouraged from reaping the full benefits of the new technology.

APPENDIX

Relationship between the deposition of iodine-131, caesium-137 strontium-89 and strontium-90 in finely divided freely soluble form and internal doses to the population due to dietary contamination

The exposure of infants is considered since, especially if they consume fresh milk, they could receive the highest doses due to local contamination; a milk intake of 0.7 litres per day is assumed. Except for strontium-90, calculations relate to the early period after an emergency in which the contamination of milk decreases in the manner shown in Table 2.

1. Dose from iodine-131 to the thyroid gland

UNSCEAR (1964) calculated the accumulated radiation dose (D) to the thyroid gland as follows:-

$$D = \frac{K \times I \times F \times T}{m}$$

where K = dose rate factor (0.01 m rad/day per pCi/g tissue)

I = total intake by ingestion of ^{131}I (pCi)

F = fraction of ingested ^{131}I which reaches the thyroid (0.3)

T = mean effective time of storage of ^{131}I in thyroid (11 days)

m = mass of thyroid (2 g)

The numerical values used by UNSCEAR are shown in brackets. In other calculations (MRC, 1964) F has been taken as 0.35 for infants and m as 1.8 g; these figures, being more conservative, are here used. On this basis 1 µCi delivers about 20 rad to the infant's thyroid, or 1 rad is delivered by 0.05 µCi total intake (this value is somewhat lower than that derived by the Federal Radiation Council, 1964).

The deposit of ^{131}I in pastures which will deliver this dose can be calculated from the data in Table 2. Assuming a constant intake of milk per day, it can be calculated from the Table by integration, that the total intake will be approximately 10 times the intake on the day when the concentration is highest. Hence 1 rad will be received by an infant who ingests 0.005 μCi ^{131}I on that day. Taking the daily intake of milk as 0.7 litres, the corresponding level of iodine-131 in milk is 0.007 μCi ^{131}I/litre. From Table 2 this peak concentration could result from 0.05 μCi $^{131}I/m^2$ if deposited in a finely divided soluble deposit.

2. Dose from caesium-137 to the whole body

The Federal Radiation Council (1965) have estimated that 1 μCi ^{137}Cs ingested by an infant, weight 10 kg, will deliver 0.13 rads to the whole body, i.e. 1 rad is delivered by circa 7.7 μCi ^{137}Cs.

From the data in Table 2 it can be calculated that the integrated intake of ^{137}Cs after a single release will be about 33 times the intake in milk on the day of highest contamination. Hence 1 rad will be received by an infant who consumes circa 0.23 μCi ^{137}Cs on that day; assuming an intake of 0.7 litre this corresponds to circa 0.33 μCi ^{137}Cs/litre. Table 2 shows that this level of contamination will result when the deposit is circa 1.1 μCi $^{137}Cs/m^2$.

3. Dose from strontium-89 to bone marrow

The Federal Radiation Council (1965) concluded that a mean dose of 1 rad would be delivered to bone marrow if the maximum concentration of ^{89}Sr in milk were 0.37 μCi/litre, continuous intake being assumed. From Table 2 it is evident that this level of contamination would result from the deposition of circa 20 μCi $^{89}Sr/m^2$.

4. Dose from strontium-90 to bone marrow

The dose from ^{90}Sr will be less than that from ^{89}Sr in the early period, but ^{90}Sr may continue to enter agricultural produce from the soil for a prolonged period. The long term situation is therefore considered. It is assumed in calculation that the entire diet during the period in which bone is laid down was produced in the contaminated zone.

It is assumed that the ratio of ^{90}Sr to calcium in bone is 0.25 of that in diet (UNSCEAR, 1964) and that 1 pCi ^{90}Sr/g Ca in bone delivers 0.82 m rad/year to the bone marrow of infants (MRC, 1966). Hence 1 rad/year is delivered by:

$$\frac{1 \times 10^{-6}}{0.82 \times 10^{-3} \times 0.25} = 5 \times 10^{-3}\ \mu\text{Ci}\ ^{90}\text{Sr/g Ca in diet.}$$

It has been shown (page 7) that under average conditions in the United Kingdom the presence of 1 mCi $^{90}Sr/km^2$ in the soil would lead to 0.11 pCi ^{90}Sr/g Ca in milk. Hence 5×10^{-3} μCi ^{90}Sr/g Ca will be present in milk when the deposit in the soil is:-

$$1 \times \frac{5 \times 10^{-3}}{0.11 \times 10^{-6}}\ \text{mCi}\ ^{90}\text{Sr/km}^2 = \underline{\text{circa}}\ 45\ \text{Ci}\ ^{90}\text{Sr/km}^2 \text{ or } 45\ \mu\text{Ci/m}^2$$

A deposit of 45 Ci/km^2 would therefore cause bone marrow to receive 1 rad/year.

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TABLE 1

Contribution of the critical nuclides to the total radioactivity of mixed fission products 24 hours after fission

	% of total activity
Iodine-131	0.8
Strontium-89	0.18
Strontium-90	0.0013
Caesium-137	0.0010

Based on Bolles and Ballou (1956) with adjustment for the revised half-life of ^{90}Sr (28 years).

TABLE 2

Estimated contamination of milk when finely divided freely soluble fission products are deposited on pastures from which cattle derive their total diet

μCi/litre per μCi deposited per m^2

Days after deposition	Iodine-131	Strontium-89	Caesium-137
1	0.12	0.006	0.09
2	0.14	0.013	0.17
4	0.13	0.019	0.25
6	0.10	0.019	0.28
8	0.08	0.018	0.30
10	0.06	0.016	0.29
20	0.015	0.008	0.22
30	0.004	0.004	0.15

From Russell (1966)

TABLE 3

Anticipated total dose commitments to the population of the United Kingdom from fission products other than iodine-131 released in weapon tests up to 1966

	Bone marrow (m rad)	Gonads and other tissues (m rad)
Strontium-90	40	-
Strontium-89	<0.5	-
Caesium-137: Internal	23	23
Caesium-137: External	27	27
Short-lived isotopes: External	17	17
Total	120*	80*
Approximate periods (years) in which these doses are received from background radiation	1.2	0.8

* These figures include the contribution of carbon-14, an induced activity which is expected to deliver 13 m rad before the year 2000.

Based on Medical Research Council (1966)

TABLE 4

Estimate of the quantities of the "critical" nuclides present in a deposit of mixed fission products which would deliver an external gamma dose rate of 100 R/hour 1 m above the ground surface 1 hour after fission

Nuclide	Deposition of mixed fission products	Deposition of fractionated fission products	
	$\mu Ci/m^2$ at 24 hours	Fractionation factor*	$\mu Ci/m^2$ at 24 hours
(1)	(2)	(3)	(4)
Iodine-131	3400	3	1130
Caesium-137	4	10	0.4
Strontium-89	760	5	150
Strontium-90	5	5	1

* The fractionation factors may not be applicable when the gamma dose rate is as low as 0.1 R/hour at 1 hour.

TABLE 5

Assumed physical properties of fallout in different fallout fields after the detonation of a single nuclear weapon

	Dose rate R/hour at 1 hour	Particle size (μ)	Initial retention on herbage (%)	Initial solubility (%)	Availability for transfer through food chains of debris deposited on growing crops relative to a finely divided freely soluble deposit*
(1)	(2)	(3)	(4)	(5)	(6)
Heavy	>100	100	2.5	10	0.01
Medium	10	40	2.5	10	0.01
Light	1	25	15	10	0.06
Very long range	0.1	small	25	50	0.5

* The figures in this column are the product of the ratios of values given in columns 4 and 5 to the corresponding values for a finely divided freely soluble deposit (initial retention 25%; solubility 100%), i.e. for a heavy deposit $\frac{2.5}{25} \times \frac{10}{100}$. It is to be noted that solubility should alone be taken into account with respect to long-lived nuclides which have entered the soil.

TABLE 6

Expected levels of contamination in milk and resultant tissue doses in a fallout field of 100 R/hour at 1 hour due to a single nuclear weapon

It is assumed that cattle derive their entire diet from grazing

Nuclide	Peak contamination in milk	Maximum radiation dose due to ingestion
EARLY PERIOD	μCi/litre	rad*
^{131}I	1.6	230 to thyroid glands of infants
^{89}Sr	0.03	<0.1 to bone marrow of infants
^{137}Cs	1×10^{-3}	<0.01 to whole body
ONE YEAR AFTER DETONATION	pCi/g Ca	rad/year
^{90}Sr in soil	110	<0.1 to bone marrow
^{90}Sr in current world-wide fallout per 1000 megatons fission	200	0.05 to bone marrow

* Integrated dose assuming continuing consumption of contaminated food.

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ESTIMATION OF THE INTERNAL DOSE TO MAN FROM THE RADIONUCLIDES PRODUCED IN A SURFACE EXPLOSION OF A NUCLEAR DEVICE*

-4

4.3

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A method has been developed for estimation of the internal dose to man from each and every radionuclide that is produced and released to the atmosphere following the detonation of a nuclear device. By means of this analysis

(1) the nuclides that could contribute most to the internal dose in man can be identified,

(2) the internal dose to tissues and organs of man can be estimated, and

(3) contributions of individual nuclides to this dose can be determined.

For the identification of significant radionuclides we can rely on no single criterion. Thus, we must consider the internal dose to a number of organs, and we must examine various routes of entry into man. Our general approach for estimating the internal dose from radionuclides released to the atmosphere and deposited on agricultural

*This work was performed under the auspices of the U.S. Atomic Energy Commission.

lands is described in detail in the reference paper (1). In this presentation I shall consider the application of this method to a surface explosion of a thermonuclear device. This approach deals with terrestrial food chains, and we are now extending the analysis to the entry of radioactivity into marine and freshwater food chains.

Sources of Activity

The radionuclides produced in thermonuclear explosions include fission products, activities induced in device materials, activities induced in materials surrounding the device, and tritium. Nuclides of elements distributed over the entire periodic table are released to the biosphere following a surface thermonuclear explosion. We have attempted a thorough analysis of the activities that can be produced, so that no nuclide is overlooked as a significant contributor to the internal dose. Thus we have considered the production of numerous other fission products besides the familiar I-131, Sr-90 and Cs-137, and we have considered over 200 neutron activation reactions for which activation cross-sections are available. With respect to activation of device materials, special procedures have been developed for the analysis of device activation, which consider activation by charged-particle capture and multiple neutron capture, as well as single neutron capture. These procedures are available in a publication (2) and will not be referred to further in this presentation.

The Unit-Rad Deposition

Details of the procedure for estimating the dosage from radionuclides in fallout are given in the reference paper (1), and only a brief review will be presented at this time. The basic calculation is

the estimation of the unit-rad deposition for each radionuclide that could be encountered. The unit-rad deposition F_1 is the minimum deposition that could result in a 30-year internal dose of 1 rad. The estimated dose from a given nuclide is calculated from the unit-rad deposition and from the known or predicted value of deposition.

A. Forage-to-Cow-to-Milk Pathway

The unit-rad deposition via milk is calculated using the expression

$$F_1 = \frac{(7.04 \times 10^{-8})}{(UAF)\,Qf\,T_P T_E} \quad \frac{(1 - T_P/T_E)}{(1 - T_P/T_E - e^{-20.8/T_E})} \tag{1}$$

The quantities in the expression are

F_1	unit-rad deposition
(UAF)	"utilized area factor," the effective area of pasture grazed daily by the cow
Q	energy absorbed in organ or tissue per disintegration
f	fraction of the isotope ingested daily by the cow that is deposited in man's tissue per gram
T_P	effective half-life <u>on</u> forage
T_E	effective half-life in man's tissue

This expression yields F_1 in $\mu Ci/m^2/rad$ when (UAF) is expressed in m^2/day, Q is expressed in MeV, and T_P and T_E are expressed in yr. (UAF) has been assumed to be 45 m^2/day, and the half-residence time <u>on</u> forage, which determines T_P, has been assumed to be 14 days. The f term is calculated as

$$f = f_M f_B / m \tag{2}$$

The terms in the expression for f are

f_M fraction of isotope ingested daily that is secreted in milk per liter

f_B fraction of ingested isotope that is taken up in an organ or tissue

m mass of organ (in g)

The unit-rad deposition calculated by Eq. (1) can be used to represent the situation in which man directly ingests the fallout depositing on plants by consumption of fresh fruits and vegetables. For example, if man consumes daily the fresh produce growing on an area of 0.1 m^2, the unit-rad deposition via milk is calculated with $(UAF)f_M = 0.1$. The maximum area of contamination transferred daily to a person consuming a liter of milk daily is about 2.5 m^2 (which corresponds to $(UAF)f_M = 2.5$).

Unit-rad depositions via milk have been estimated for all the isotopes listed on the "Chart of the Nuclides" (3) which have a half-life of 12 hours or greater. The unit-rad depositions were calculated for a number of tissues including bone, the gonads, and the whole body and are available for the adult and the 1-year child.

B. Soil-Root Pathway

The unit-rad deposition via soil is calculated using the expression

$$F_1 = \frac{3.71 \times 10^{-1}\,\rho\, d}{Q}\left(\frac{C_S}{C_B}\right)\frac{1}{\left[T_R\,(1-e^{-20.8/T_R}) - T_E\,(1-e^{-20.8/T_E})\right]} \qquad (3)$$

The quantities in the expression appearing for the first time are

ρ density of soil (plow layer)

d depth of plow layer

C_S concentration of stable isotopes in soil

C_B concentration of stable isotopes in organ or tissue

T_R half-life for radioactive decay

This expression yields F_1 via soil when ρ is expressed in g/cm^3, d is expressed in cm, Q is expressed in MeV, and T_R and T_E are expressed in yr. ρ has been assumed to be 2 g/cm^3, and d has been assumed to be 20 cm.

Unit-rad depositions via soil have been estimated for every isotope whose half-life is 30 days or greater. The F_1 values are available for the adult and infant organs considered via the forage-to-cow-to-milk pathway. In calculating the F_1 via soil for infants, the T_B for all radionuclides was set equal to zero. Since the infant experiences rapid growth and development, his body tissues have been assumed to equilibrate very rapidly (instantaneously) with his diet and the environment (soil) from which his diet is derived.

The unit-rad depositions rank the radionuclides in the order of their contribution to the internal dose under conditions of equal deposition. Under these conditions the estimated dose from a radionuclide will vary inversely with its unit-rad deposition. The estimated dose from a given deposition is simply the quotient of the deposition in $\mu Ci/m^2$ and the unit-rad deposition.

The Meter^2-Rad

The dose from radionuclides released to the atmosphere in a surface nuclear detonation can be estimated from the activities produced and the fraction released to the atmosphere and deposited on agricultural

land. In this procedure we first determine the m^2-rad based on the total activity produced. As shown below, the m^2-rad is the quotient of the activity produced in the detonation expressed in μCi and the unit rad deposition F_1, which is expressed in $\mu Ci/m^2/rad$.

$$\Sigma\ (m^2\text{-rad}) = P\ (\mu Ci)/F_1\ (\mu Ci/m^2/rad) \tag{4}$$

Σ is the m^2-rad and P, the activity produced. The m^2-rad value can be regarded as the estimated dose in rads resulting from total deposition of the activity on an area of 1 m^2. Alternatively, it can be regarded as the minimum area in m^2 over which uniform deposition can be allowed to occur for a dose not to exceed 1 rad. The estimated dose ED is the product of m^2-rad and the fractional deposition. The fractional deposition EC is the fraction of the activity produced that is deposited per m^2 and is expressed in units of m^{-2}. Thus

$$ED\ (rad) = \Sigma\ (m^2\text{-rad}) \times EC\ (m^{-2}) \tag{5}$$

A special-purpose Handbook has been prepared for use in estimating the internal dosage by this method (4). The Handbook, which is to be continuously updated and is to be expandable, lists the unit-rad depositions via milk and via soil and the input parameters used for their calculation. Worst-case estimates were made for the input parameters not directly obtainable from the ICRP Tables and other literature sources. When worst-case estimates led to the identification of potentially hazardous nuclides, that is, nuclides whose m^2-rad values were within the first three orders of magnitude, more reasonable values based on collateral data were obtained where possible. The use of collateral data for the evaluation of input parameters is described in detail in the Appendix of the Handbook. The parameters for additional

elements beyond those represented in the first three orders of m^2-rad values will be reevaluated in future updatings of the Handbook, and the data for the aquatic environments will be included.

Following this approach, most radionuclides can be eliminated from consideration and relatively few are singled out as the most hazardous. Our final results will therefore reveal a nuclide to be significant because of 1 of 2 reasons: either (1) it can be a potential hazard because of what we know about it, or (2) it can be a potential hazard because of what we don't know about it. To illustrate this point, the unit-rad depositions of Na-24 and Ir-192 for the child's whole body via milk are the same. While the unit-rad depositions are equal, the m^2-rad for the Na^{24} produced by neutron activation of granite exceeds by a factor of 10^6 the m^2-rad for the Ir-192 produced (1). The estimated dose from Na^{24} would exceed that from Ir^{192} by the same factor. Obviously, relative to the dose from Na^{24}, the dose from Ir-192 can be considered insignificant.

Meter^2-Rad of Fission Products and Soil Activation Products

I shall present as examples m^2-rad values for the significant nuclides produced by fission and by neutron activation of soil. In the

tables to follow the m^2-rad values are presented in decreasing order; only the highest values are shown.

A. Forage-to-Cow-to-Milk Pathway

Table I shows the m^2-rad via milk to the whole body and bone of the 10-kg child per kt of Pu-239 fission. The m^2-rad were calculated using the highest fission yields (fission by 14 MeV neutrons) listed by Weaver (5). The m^2-rad for the other fissionable species would not differ significantly for present purposes. The input parameters of most of the nuclides are well known, so that the m^2-rad values are largely reasonable, and the m^2-rad totals are reasonable.

The internal dose from a fission product released in a nuclear detonation can be estimated from the fission yield and the appropriate fractional deposition. If Y is the fission yield in kt, the estimated dose from a given isotope would be

$$ED\ (\text{rad}) = \Sigma\ (m^2\text{-rad/kt}) \times Y\ (\text{kt}) \times EC\ (m^{-2}) \qquad (6)$$

Let us assume, purely for illustrative purposes, that the appropriate fractional deposition for I-131 and each of the other fission products from a surface detonation at a given time and location is $10^{-11}\ m^{-2}$. Then the estimated dose to the child's whole body from the I-131 would be 0.3 rad and the total estimated dose from all the isotopes would be about 1 rad. If the fractional deposition of the isotopes differed, the estimated doses for the isotopes would be determined individually and then summed to obtain the total.

Table I. Meter^2-rad via milk to the child's whole body and bone from Pu-239 fission products

Radionuclide	Half-life	Σ (whole body) m^2-rad/kt	Σ (bone) m^2-rad/kt
I 131	8.05 d	3.1×10^{10}	1.6×10^{10}
Cs 136	13 d	2.6×10^{10}	2.6×10^{10}
Ag 111	7.5 d	1.9×10^{10}	1.2×10^{10}
I 133	21 h	1.4×10^{10}	1.1×10^{10}
Mo 99	66 h	9.8×10^{9}	1.4×10^{10}
Sr 90	28 y	2.1×10^{9}	1.8×10^{10}
Sr 89	50.4 d	1.6×10^{9}	1.2×10^{10}
Cs 137	30 y	1.3×10^{9}	1.3×10^{9}
Te 132	78 h	9.2×10^{8}	1.0×10^{9}
Ba 140	12.8 d	4.4×10^{8}	3.3×10^{9}
Sn 125	9.4 d	2.0×10^{8}	8.7×10^{8}
Total		1.1×10^{11}	1.2×10^{11}

The second source of radionuclides is neutron activation of environmental materials surrounding the device. Table II shows the m^2-rad via milk to the child's whole body and bone from the neutron activation products produced in soil per mole of 14 MeV neutrons. Neutron activation of soil by a surface nuclear explosion is represented by the values previously calculated for neutron activation of granite by an underground nuclear explosion (1, 6). The concentrations of the parent nuclides differ in granite and soil, but the differences in concentration are not significant for present purposes in view of all the other uncertainties. The input parameters of the nuclides listed in Table II are also well-known and hence their m^2-rad are reasonable.

Let us consider the m^2-rad values of the activation products in relation to the yield of the device. The neutron yield per Mt of fusion is about 10^{27} neutrons (7). Thus if all of the neutrons produced in a 1 Mt fusion explosion were released to the environment, the m^2-rad per Mt of fusion would be about 1000 times the m^2-rad per mole. If 10% of the neutrons were released to the environment, the m^2-rad per Mt of fusion would be about 100 times the m^2-rad/mole. The estimated dose from individual isotopes and the total estimated dose are determined from the appropriate fractional depositions, as in the case of the fission products, and from Z, the number of moles of neutrons released to the environment. Thus

$$\mathrm{ED\ (rad)} = \Sigma\ (\mathrm{m^2\text{-}rad/mole}) \times Z\ (\mathrm{mole}) \times \mathrm{EC}\ (\mathrm{m^{-2}}) \qquad (7)$$

Table II Meter^2-rad via milk to the child's whole body and bone from activation products produced in soil by a surface nuclear explosion (14 MeV neutrons).

Radionuclide		Half-life		Σ (whole body) m^2-rad/mole	Σ (bone) m^2-rad/mole
Na	24	15	h	4.3×10^{11}	4.3×10^{11}
P	32	14.3	d	3.8×10^{9}	2.2×10^{10}
K	42	12.4	h	3.8×10^{9}	3.8×10^{9}
Rb	86	18.7	d	3.8×10^{9}	3.8×10^{9}
Rb	84	33	d	2.8×10^{9}	2.8×10^{9}
Cs	134	2.1	y	8.8×10^{8}	8.6×10^{8}
Na	22	2.58	y	3.7×10^{8}	3.7×10^{8}
Ca	45	165	d	3.3×10^{8}	3.1×10^{9}
Br	82	35.3	h	1.2×10^{8}	1.2×10^{8}
Total				4.5×10^{11}	4.7×10^{11}

B. Soil-Root Pathway

Table III shows the m^2-rad via soil per kt of Pu-239 fission calculated for the infant's whole body and bone, while Table IV shows the m^2-rad via soil to the infant's whole body and bone from activation products produced in soil per mole of 14 MeV neutrons. The estimated doses from the individual isotopes and the total estimated doses are again determined from the appropriate fractional depositions as illustrated above for fission products via milk.

Table III. Meter^2-rad via soil to the child's whole body and bone from Pu-239 fission products.

Radionuclide	Half-life	Σ (whole body) m^2-rad/kt	Σ (bone) m^2-rad/kt
Ru 106	1 y	5.0×10^8	2.5×10^9
Cd 113m	14 y	1.5×10^7	1.0×10^7
Sr 90	28 y	1.7×10^6	3.7×10^7
Sb 125	2.7 y	8.3×10^5	3.2×10^6
Ce 144	285 d	7.6×10^5	7.6×10^6
Cs 137	30 y	3.7×10^5	1.0×10^6
Sn 119m	250 d	1.5×10^5	2.5×10^6
Pm 147	2.7 y	1.5×10^5	1.5×10^6
Sn 121m	~ 25 y	1.4×10^5	2.2×10^6
Total		5.2×10^8	2.5×10^9

Table IV. Meter^2-rad via soil to the infant's whole body and bone from activation products produced in soil by a surface nuclear explosion (14 MeV neutrons).

Radionuclide		Half-life		Σ(whole body) m^2-rad/mole	Σ(bone) m^2-rad/mole
Na	22	2.58	y	5.8×10^6	3.1×10^7
Cl	36	3×10^5	y	1.4×10^5	1.2×10^5
Zn	65	245	d	1.1×10^5	3.6×10^5
Co	60	5.26	y	3.9×10^4	7.9×10^6
Cs	134	2.1	y	3.9×10^4	1.2×10^5
Eu	152	12.4	y	2.9×10^4	2.9×10^5
Tl	204	3.8	y	1.3×10^4	1.5×10^4
Total				6.0×10^6	4.0×10^7

Estimated Dose from a Surface Detonation of a Thermonuclear Device

The first step in the estimation of the internal dose is the determination of the total m^2-rad value for the device in question. We shall assume a 1 Mt thermonuclear device detonated at the surface. It will be assumed that this device has a 500 kt fission yield and a 500 kt fusion yield (8). Furthermore, it will be assumed that 20% or 1×10^{26} neutrons escape the device and are captured in the environment (9). Half of these neutrons or 5×10^{25} are assumed to be captured by the soil. The total m^2-rad values for such an explosion are then given by Eqs. (6) and (7) where $Y = 500$ and $Z \approx 100$.

The estimated internal dose from a given isotope is determined from the m^2-rad using the appropriate fractional deposition. It is not

the purpose of this paper to discuss the appropriate fractional deposition values for use in predicting the dosage from fallout. This is properly the subject of Session I of this Symposium. Nevertheless, it may be worthwhile to consider the magnitude of the estimated internal doses on the basis of fallout levels that have been encountered subsequent to testing at the Nevada Test Site.

Nuclear devices detonated at the Nevada Test Site for the most part injected radioactivity into the troposphere and lower stratosphere. It is estimated that a land surface burst in the megaton range would inject up to 50% of the radioactivity into this region of the atmosphere (10). We therefore shall assume that 50% of the activity produced in the detonation will produce fallout situations that are comparable to those previously observed following the Nevada tests.

Tamplin has shown that measurements of wet deposition following the Nevada tests would lead to the relationship between fractional deposition and time of deposition shown in the table below (11):

Table V. Fractional deposition as a function of post-detonation time. (11)

t (hr)	EC (m^{-2})	t (hr)	EC (m^{-2})
1	2×10^{-9}	72	1×10^{-13}
6	3×10^{-11}	96	5×10^{-14}
12	4×10^{-12}	120	4×10^{-14}
24	5×10^{-13}	144	3×10^{-14}
48	2×10^{-13}		

These EC values have been corrected for the 50% fraction of the debris injected into the troposphere and lower stratosphere. These fractional depositions can be combined with the m^2-rad values and the Y and Z terms of Eqs. (6) and (7) to obtain the estimated doses from our hypothetical 1 Mt detonation.

Table VI shows the resulting estimated dosage via milk to the child's whole body and bone. While the individual isotopes differ in their contributions to the doses, the total estimated doses to the whole body and bone are seen to be similar. The estimated dosage from fission products is 30 rads at 1 day and is still 2 rads at 140 hr or 6 days. The dosage from soil activation products is 10 rads at 1 day and 0.01 rad at 6 days. The doses from activation products decrease

Table VI. Estimated dose to the child via milk from a hypothetical 1-Mt surface explosion of a thermonuclear device.

Time of deposition t (hr)	Fission Products: bone ED (rad)	Fission Products: whole body ED (rad)	Fission Products: thyroid ED (rad)	Activation Products: bone ED (rad)	Activation Products: whole body ED (rad)
6	1,800	1,700	62,000	1,100	1,000
12	240	220	8,300	110	110
24	30	28	1,000	9	8
48	12	11	350	1	1
72	6	6	190	0.4	0.3
96	3	3	120	0.2	0.1
120	2	2	85	0.1	0.06
144	2	2	64	0.1	0.04

rapidly as a result of Na-24 decay. The dosage shown for fission products and soil activation products can be scaled up or down to represent the doses resulting from fission and fusion yields and escape fractions of neutrons differing from those assumed.

Also shown in Table VI is the estimated dosage via milk to the child's 2-g thyroid. The estimated dosage to the child's thyroid is based on a reasonable and carefully considered F_1 via milk of 3.3×10^{-2} $\mu Ci/m^2/rad$ (12). The estimated thyroid doses are seen to vary from upwards of 1000 rads down to 60 rads. It is important to point out that in 6 days radioactive debris from the detonation can travel halfway around the world. In other words, any milk produced within the latitude band of the explosion could be contaminated well above existing guidelines.

Table VII shows the estimated maximum doses via soil to the infant's whole body and bone. In contrast to the estimated doses via milk, these doses are measured in rad and fractional rad units. The estimated doses to bone are seen to exceed those to the whole body.

In an actual situation the total estimated dose is obtained as the sum of the estimated doses from the fission products and the induced activities. Table VIII shows the total estimated dosage via milk and

Table VII. Estimated dose to the infant via soil from a hypothetical 1-Mt surface explosion of a thermonuclear device.

Time of detonation t (hr)	Fission Products bone ED(rad)	Fission Products whole body ED(rad)	Activation Products bone ED(rad)	Activation Products whole body ED(rad)
6	23	8	0.12	0.02
12	3	1	0.02	0.002
24	0.4	0.1	0.002	3×10^{-4}
48	0.15	0.05	8×10^{-4}	1×10^{-4}
72	0.08	0.03	4×10^{-4}	6×10^{-5}
96	0.04	0.02	2×10^{-4}	3×10^{-5}
120	0.03	0.01	2×10^{-4}	2×10^{-5}
144	0.02	0.008	1×10^{-4}	2×10^{-5}

Table VIII. Total estimated dose to the child or infant from a hypothetical 1-Mt surface explosion of a thermonuclear device.

Time of deposition t (hr)	Via milk bone ED(rad)	Via milk whole body ED(rad)	Via milk thyroid ED(rad)	Via soil bone ED(rad)	Via soil whole body ED(rad)
6	3,100	2,900	62,000	23	8
12	360	340	8,300	3	1
24	40	38	1,000	0.4	0.1
48	14	12	350	0.2	0.05
72	7	6	190	0.08	0.03
96	3	3	120	0.04	0.02
120	3	2	85	0.03	0.01
144	2	2	64	0.02	0.008

via soil to the whole body and bone resulting from our hypothetical detonation. The estimated dosage to the thyroid from I-131 is also included in Table VIII. These figures indicate that under conditions of normal agricultural practice substantial internal dosages could be experienced at very large distances from the site of detonation.

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This paper is based on publications of the UCRL-50163 series (1, 2, 4, 11). Additional reports of this series are forthcoming for the analysis of radioactive contamination of aquatic environments.

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L

RADIATION RISKS FROM DIFFERENT INTERNAL AND EXTERNAL SOURCES AFTER LOCAL FALLOUT

4.8

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A b s t r a c t

An attempt is made to compare the radiation doses received after local fallout through external radiation, inhalation, and consumption of drinking water, vegetables, milk, eggs and fish, as a function of fission yield, time and distance on the basis of an idealized fallout pattern and supposing that no countermeasures are applied. The results are presented in the form of a simple tabulation which enables one to make rapid comparisons of different sources of the maximal radiation risks at the conditions specified in the study.

Introduction

Civil defence authorities have to make decisions within hours or days, and to give instructions, not only on the residence time in civil defence shelters, but also on the utilization of surface water for drinking and the consumption of vegetables, milk, eggs and fish after local fallout. The importance of different food items has been studied by several authors, but the situation tends to be complicated, as the contribution of different sources to the radiation dose varies with time and distance. In this study the radiation doses from the above sources are estimated as a function of fission yield, time and distance on the basis of the idealized local fallout pattern from a 1 MT fission yield burst at 25 km (15 mi) per hour wind speed / 1 /. They are compared supposing that no protective measures are used in any case.

The basis of estimations

1. External radiation

The risks of external radiation have been estimated under the condition, that the unsheltered individual is exposed to the radiation resulting from local fallout and decreasing with time $t^{-1.2}$ / 1 /.

The radioactive cloud is assumed to be transported by an effective wind speed of 25 km (15 mi) per hour. The unit-time reference dose rate can be obtained from the idealized dose rate pattern given by Glasstone /ref. 1, p. 449/. The integrated radiation dose received from early fall-out during any specified stay can then be estimated by using the unit-time dose rate multiplying factor /ref. 1, p. 429/.

For instance, a 1 MT surface burst at a 25 km distance gives a unit-time dose rate of 3.100 r/h. The multiplying factor for a 1 day's stay is 2.3 and the total dose during 1 day is 7.1 kr.

2. Internal radiation

The consideration of internal radiation hazards, e.g. the hazard resulting from inhalation or ingestion of radioactive substances, is limited to radioactive iodine, because of its over-riding biological importance during the first month after the disaster. The thyroid doses given are hypothetical maximum values as no reductions have been applied for nonretention of fallout particles on the herbage or for fractionation or insolubility of the isotopes of radioiodine in the particles. Thus the figures of the thyroid doses are likely to be 1 to 2 orders of magnitude too high for the closest ranges where the large particles dominate, but become realistic at the intermediate ranges where fine particles dominate, as well as for fresh "washouts". Thus these figures represent the worst possibility.

The estimation of the doses from inhalation and consumption of milk and eggs is deduced from an assessment of hazards arising from a release of fission products following a reactor accident, reported by Beattie / 2 / on the basis of data from the Windscale accident and laboratory scale tests reported in the literature. Fig. 10 in ref. 2 gives the important ranges of hazard from a volatile release in average weather conditions and thus enables an evaluation of the radiation doses from different sources relative to the external radiation dose. To obtain the doses resulting from inhalation, milk and eggs, the external radiation dose constituted by the radiation from the cloud and the ground deposition must be multiplied by the conversion factors of 54.5, 8710 and 436.

As the activity released in a reactor accident mainly consists of iodine, the above dose values must be reduced by a factor representing the time dependent share of iodine isotopes of the total activity after a nuclear detonation / 3 /.

- Inhalation. The thyroid dose through inhalation of radioactive material is caused by the isotopes of iodine that have entered the blood stream throught the lungs and the gut. According to the 1959 Recommendations of the I.C.R.P. / 4 / the uptake of iodine from the gut to the blood stream is 100 % while the uptake by inhalation to the blood stream is 75 %.

The calculated inhalation doses are valid for children 0-5 years of age as the small size of the thyroid gland makes this population group critical.

The residence time of the radioactive cloud is supposed to be 1 h. For example, a 1 MT detonation at a 25 km distance with a unit-time dose rate of 3 100 r/h for a 1 h stay, gives a unit-time multiplying factor of 0.6 and consequently an external radiation dose of 1 860 r. The thyroid dose through inhalation for this time is 1860 x 54.5 x 9 % = 9.1 kr, 9 % being the iodine percentage of the total activity (including the shortlived iodine isotopes).

- Drinking water. The drinking water dose figures represent the thyroid doses received by the average consumer of the water from a 3 m deep reservoid, as calculated by Hawkins / 5 /.

- Vegetables. During the summer, fresh vegetables may represent a significant part of the contaminated intake, as recently pointed out by Thompson / 6,7 /. A conversion factor for the evaluation of the vegetable dose from the external radiation dose amounting to 10 % of the milk conversion factor, e.g. 10 % · 8710 = 871 appears to be in accordance with Thompson's calculations. For a 1 MT detonation at a 25 km distance the thyroid dose through vegetables during the first day becomes 7.1 x 871 x 9.7% = 600 kr, assuming a daily consumption of 60 g.

- Milk. Most of the fallout iodine reaches man through the alimentary chain grass - cow - milk - man. The figures for the thyroid doses through milk are to be applied on the six month old infant, who is at greatest hazard owing not only to a small thyroid weight, but also to an enhanced milk consumption and iodine uptake factor. The milk doses have been calculated for early summer when cattle commonly do not get supplementary feeding. A milk consumption of 1 liter per day is assumed.

- Eggs. The thyroid doses received from eggs are also valid for a child, six months of age, who is supposed to eat one egg a day.

- Fish. The estimation of the doses received from fish is based on tracer experiments with ^{131}I in Finnish lakes, carried out in the summer of 1967 / 8 /. The values apply to the accumulation of ^{131}I into Crucian carp from a eutrophic (nutrient rich) lake, which is believed to be a representative case. Further assumptions of a daily fish intake of 200 g and a fresh water intake of 2.2 liters per day give a fish - water dose conversion factor of 51.9 for the first week and 68.1 for the period 1 week - 1 month.

Conclusions

The schematic tabulations of the present study are intended to give a rough comparative estimation of the order of magnitude of the different radiation hazards. As long as no measured results, or merely external dose rate values, are available, such tabulations are necessary for the civil defence authorities as a reference when making decisions. The first direct measurements of the victuals enable more accurate hazard estimations than those provided by these tables.

Obviously, milk is the most critical factor, constituting an about 10 times greater hazard than vegetables or eggs, while the thyroid dose from these two sources is about 100 times greater than the total body dose from external radiation, or the thyroid dose from fish. The dose obtained from drinking water is of little importance in most instances. The values of this study represent the worst possibility as no countermeasures are supposed and no reduction of radioiodine due to fractionation or biological nonavailability is supposed.

It is quite evident that, in the case of local fallout, protective measures have to be taken against all the risks dealt with in this study. When such measures are being planned, these tables may provide some guidance for a rapid estimation of the most critical risks, as a function of time and distance.

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Table 1.   Dose received between arrival and 1 day

1 MT

Time of arrival (h)	Distance	External radiation (shelter factor 1)	Inhalation (thyroid dose)	Drinking water (thyroid dose)	Vegetables (thyroid dose)
1	25	7.1 kr	9.1 kr	150 r	600 kr
6	150	180 r	95 r	3.7 r	18 kr
12	300	27 r	12 r	0.6 r	2.9 kr
		20 MT			
6	150	3.6 kr	1.9 kr	74 r	360 kr
12	300	540 r	240 r	11 r	57 kr

Table 2. Dose received between 1 day and 1 week

1 MT

Distance (km)	External radiation (shelter factor 1)	Drinking water (thyroid dose)	Vegetables (thyroid dose)	Milk (thyroid dose)	Eggs (thyroid dose)	Fish (thyroid dose)
25	2.8 kr	85 r	350 kr	3.5 Mr	170 kr	4.4 kr
150	140 r	4.4 r	18 kr	180 kr	9.0 kr	230 r
300	32 r	1.0 r	3.9 kr	39 kr	2.0 kr	52 r
			20 MT			
150	2.9 kr	88 r	360 kr	3.6 Mr	180 kr	4.6 kr
300	630 r	19 r	79 kr	790 kr	39 kr	1 kr

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Table 3. Dose received between 1 week and 1 month

1 MT

Distance (km)	External radiation (shelter factor 1)	Drinking water (thyroid dose)	Vegetables (thyroid dose)	Milk (thyroid dose)	Eggs (thyroid dose)	Fish (thyroid dose)
25	1.6 kr	43 r	170 kr	1.8 Mr	88 kr	2.9 kr
150	90 r	2.4 r	9.9 kr	100 kr	5.0 kr	160 r
300	20 r	0.5 r	2.2 kr	22 kr	1.1 kr	34 r
			20 MT			
150	1.8 kr	49 r	200 kr	2.0 Mr	100 kr	3.2 kr
300	400 r	1.1 r	44 kr	440 kr	22 kr	680 r

E

PROTECTION OF HOSPITALS IN CASE OF NUCLEAR FALLOUT

5.2

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Introduction.

Hospitals are sensitive to wartime damages and nuclear fallout. Their working capacity and standard of medical care are easily reduced and this is likely to happen just when hospitals are needed at most. From the point of protection of the public, hospitals should be able to continue their work at highest possible capacity and medical standard as long as the population is not evacuated from the area. From this follows that hospitals should be well protected and possibly to a better standard than what is paid on protection in general in that area.

Radiation whole body gamma doses are the critical factor of consideration, especially during the survival phase caused by heavy local fallout. Second factor of importance in the survival phase is related to contamination of the internal hospital facilities and thirdly that of internal contamination of humans through contamination of air, drinking water etc. The priority of countermeasures to be taken in the survival phase is thereby given. They will be discussed in some detail in the following.

Minimum gamma radiation shielding for hospitals.

These factors can be discussed in several ways. In the following a discussion is based on the mentioned relation between working condition for the hospital and the survival protection standard of the population in the area. For planning purposes Civil Defence in Norway often sets 70 rads whole body dose as action limit to individuals in course of an 48 hour exposure. The average home shelter shielding factor is estimated to 40. This defines an area to be evacuated 48 hours after detonation (Z-zone, H + 48). If same dose limit is to be accepted to individuals at the hospital at H + 48, no occupied space in the hospital can have smaller shielding factor than 40. If anyone has to remain in the hospital for a day or two, their protection should not have been less by a factor of 100 or so. The same factor of 100 would on the other hand give more time for the evacuation out of the radiation area. The transport of patients on stretchers out of a Z-zone area is likely to be a slow action due to road blocades etc. One might therefore state that if a protection factor of 40 is to be accepted for patients that can walk well and parts of the hospital staff, a factor of 100 should be given to patients confined to bed and their staff in order to balance the risks between these two groups. In any case it is evident that gamma shielding factors of 40 (100) in hospitals are too small to ensure continous operation of the hospital in a Z-zone and hardly in a Y-zone even by changing staff with staff from a non-exposed hospital.

Patients are often more sensitive to irradiations than are healthy persons. Also vital medical staff should be given protected working conditions to such a standard that their working capacity is not reduced by personnel radiation illness. In this respect it is to be remembered that medical staff

is likely to receive some doses from their handling of contaminated patients and items. The extra protection factor needed to meet the points mentioned, has not been discussed in detail, a factor of 2 has been used in the following. We therefore end up to factors of 80 for walking patients and hospital staff in general and 200 for patients confined to bed and vital medical staff as minimum factors.

The discussion so far applies to smaller hospitals and can be of guidance for the evaluation of the usefulness of existing hospitals or the setting up of secondary hospitals at the country-side in schools etc. One can argue that in given cases these minimum shielding factors arrived at are critically small or evidently too small. If a number of hospitals are likely to be seriously affected by one and the same fallout, improved radiation protection conditions should be given to some of them or to all of them. The same also applies to hospitals that are of special importance either due to capacity or other reasons or are isolated situated in remote areas where an evacuation hardly can be effective. To what extent a given area is likely to be hit by heavy fallout is not discussed in this paper, but responsible authorities might base priority for hospital protection based on such assumptions as well.

Hospital shelter occupancy problems.

A number of hospitals already have permanent shelter installation that are constructed to give protection also against blast effects etc. In general these shelters will give full radiation protection with shielding factors of several hundreds all over the shelter area. In contrast, in buildings with generally poor shielding, high shielding factors are likely to be found located only to corners etc. with good shielding geometry. In particular this applies to basements with little overhead shielding. Considerably higher shielding factors can often be achieved lying down in a corner of a basement room than staying in the middle of the same room.

Detailed knowledge of gamma radiation intensities inside the hospital building is vital to all planning to be made by the hospital management, not only for the survival administration, but also for the planned reoccupation of rooms etc. outside the shelter area. One important factor of consideration is the probable overcroudness in the shelter area and the need for releasing walking patients and parts of the staff to partial or permanent stay in other parts of the building where sufficient shielding can be found. Such a release will not only be welcomed, but might be a need for the survival of the badly wounded etc. who has to remain in the main shelter where temperature, humidity and medical caretaking due to overcroudness otherwise would be very unfavorable. The administration of "extreme corner sheltering" should therefore be studied by hospital management.
The ventilation of shelters can be a very serious problem if the stay has to be prolonged. It is evident that contaminated air from outside has to be let in if no other air supplies are available. However, unless windows etc. have been broken by blast effects, the contained air volume of the building will be contaminated only to a much smaller extent. Indoor ventilation by letting interior doors open and releasing people every hour or so for a five minutes walk and relaxe, having a quick shower etc., can make the shelter stay tolerable under otherwise bad conditions. Permission to visit other parts of the building must be well planned in order not to make the penalty

dose by leaving the shelter too great. Selected windows for ventilation purposes should be fitted with some form of dust filtration, however, ventilation all over should preferably be done under or shortly after the fall of rain or snow.

Reducing whole body exposure.

A survey of all hospital buildings should be made as part of the emergency planning with listing of the probable shelter factors in the various parts of the buildings. This survey should also have in mind where and how shielding factors can be increased and list them in works that can be arranged on short notice or by provisional means, and in such arrangements that will have to be considered as permanent parts or installations. It is clear that the old-fashioned hospitals with heavy stone exterial walls, with relatively small windows and above all, with corridors in the middle are favorable from a radiation shielding and blast protection point of view compared to the "all glass" construction often seen to day. Of great importance is also the possible shielding and reduced source effect caused by the mutual effect from buildings closely situated or from nearby topographic structure. In litterature and Civil Defence publications, shelter and radiation shielding construction can be studied and shall not be discussed here, among these are the ways of increasing overhead mass of basements. However, a few often more or less overlooked provisional means of increasing shielding, reducing indoor contamination and outdoor decontamination shall be mentioned.

a. Increasing the shielding by quick and provisional means can be done by stacking sandbags in selected windows and doors, at the end of corridors, in front of basement windows etc. In areas with good snow coverage, exterial walls of basement and of ground floor can be given additional shielding by bulldozing snow against the walls. At the same time, by spraying water, a compact and longlasting snowstructure can be made with density 0,5 or more. Besides, one should not carry out the usual clearing of the roof but let the snow remain.

b. Indoor contamination will cause an increase in total gamma radiation intensities. Even a contamination relative to outdoor ground activity of a few persent can give a significant added whole body exposure. As long as the integrity of the buildings is not destroyed, such indoor contamination ought to be avoided by keeping all doors, windows and non-filtered ventilation systems closed during arrival of the fallout and the first time thereafter. The hospital emergency team should whenever possible carry out integrity inspections immediately after every detonation causing blast- or shockwaves at the premisses. The inspection however, is likely to be interrupted as soon as heavy exposure risks are beeing noticed by their radiation instruments. Broken windows can be sealed by sheets of plastic, using tape for the lining or preferably by prefabricated and stored emergency shutter devices.

   Indoor contamination control is also very important after the deposit of the radioactive fallout. Special contamination barriers are to be arranged when communication with surroundings starts. A step by step barrier system can be necessary where the hospitals kitchen, wardrooms, dormitories etc. are behind the innermost barrier. The receiving of

contaminated patients etc. should as far as possible be canalized by the barrier system, but final decision in this respect will depend on the receiving doctors examination of the patients at the first barrier. Stocks of plastic bags should be held for the storage of patients contaminated clothings. Especially the work at the first barrier can be a rather exposed one and protective clothing and some form of dosage control should be applied. Frequent or allmost continuous decontamination (washing) of barrier areas etc. should be carried out.

c. Outdoor decontamination can have a significant reducing effect on indoor gamma radiation intensities. A favourable condition exists when the ground area between closely situated buildings is covered by asphalt as often is the case for backyards etc. Using firehoses preferably combined with scrubbing with added soap or detergents, such an area can be decontaminated by a factor of about 10 in very short time if well planned. Hosing down the roofs and window recesses is also of importance. In this way reoccupation of rooms facing this backyard can be done at a far more earlier stage.

   The ground could as a part of preplanned emergency step be covered by plastic sheets in much the same way as done in modern agriculture in nordic countries. Removing the plastic carefully would be a way of decontaminating that area. In wintertime the snow could be removed from the nearby ground, however, this and also earthscraping is believed to be less efficient and a slow and relatively more exposed job. As outdoor decontamination work does not influence space or personnel for the medical duties but can have a considerable improving effect on the hospital capacity, this type of countermeasures should be given high priority where and when conditions are favourable. Of course, outdoor contamination works as described are to be well organized and supervised in order to avoid overexposure of the personnel doing the job. The use of protective clothings and possibly dust respirators is mandatory in areas with higher contamination.

Hospital emergency planning.

Hospital duties in emergency situations are to be planned, organized and drilled in order to be effective on short notice. Problems to be covered are ranging from medical caretaking in case of mass disasters to the supplies of food, water, medicines and electricity. As far as possible, medical staff should not be engaged in non-medical duties in emergency situations.

Nuclear fallout situations call for further planning. A number of them have been discussed in this paper so far, a few more will be mentioned here.

a. Vital medical and technical staff should be given quarter at or very near the hospital.

b. A hospital emergency control office should be set up located in the shelter area. The office shall be equipped to act as hospital command center, having telephones, mains/battery operated radio receiver, maps etc. and drawings of the hospital and technical installations and a gamma reading instrument preferably with the detector outside in the open and with the possibility to be left on continously. Its sensitivity should go from nearly normal background to several hundred R/hr. An instrument that has recorder output and also alarmsettings is to be recommended. Except for the recorder, battery operation of the instrument must be possible. As soon as the control office is established

it should be known to all responsible personnel in the hospital and to Civil Defence and community and health authorities and remain in regular contact with these.

c. Hospital emergency team to deal with firefighting, decontamination, technical and other type constructive and repair work and radiological surveys should be organized and given protective clothings etc. In large hospitals with more than one building, team might be set up in each of the buildings. A close cooperation with local Civil Defence is necessary especially if the hospital is short of radiological survey instruments or expertise.

d. Plans for the evacuation of the hospital should be made in cooperation with the local authorities. Appointments on prompt and direct information on all radiological situations should be made with local Civil Defence.

e. X-ray films are sensitive to fallout radiations and are quickly destroyed unless exceptionally well shielded and contamination-free storage room can be arranged. The extensive use of fluoroscopy should be planned including the necessary X-ray personnel protection items.

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PROTECTIVE AND REMEDIAL MEASURES TAKEN FOLLOWING THREE INCIDENTS OF FALLOUT

5.3

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The stated topic of this symposium is, "We want to discuss the radiation protection measures after a nuclear mass disaster by which large areas have become so severely contaminated with radioactive material that it constitutes a major hazard for the public." Fortunately it is not possible to document directly this topic because such an event has never occured. We are forced then to look for other situations that may provide relevant information and guidance to our discussions.

There were three incidents that occurred following atmospheric nuclear weapons test detonations, and although they have been reported previously, bear recounting for they do show (a) what decisions were made and on what bases (b) the manner in which the decisions were carried out and (c) the results of the protective actions taken. (Figure 1)

There was a relatively heavy fallout on the Marshall Islands in the Pacific following an atomic test detonation on March 1, 1954 that required the evacuation of 239 inhabitants. There was also a situation in 1953 when, as a precautionary measure, about 4500 persons in St. George, Utah were asked to remain indoors for a period of two hours and in 1962 countermeasures were instituted by local and state health authorities in Salt Lake City in the State of Utah to reduce the levels of iodine-131 in the milk consumed by the public.

The Pacific incident in 1954 illustrates the necessity of, and benefits to be derived from, good safety plans that are fully implemented. The St. George, Utah incident in 1953 shows the favorable results from a program of education of local officials and the public and the close cooperation with the local authorities. The Salt Lake City, Utah incident in 1962 demonstrates the need for radiation protection guides that are clearly understood by all concerned and the necessity to monitor directly for the type of data required (such as iodine-131 in milk) rather than attempt to predict by extrapolating and reinterpreting other kinds of data.

A part of this presentation is given in first person in the hope of making the recounting of the incidents more interesting and to bring out certain points more vividly.

The Pacific Incident

On March 1, 1954 a 15 megaton[1.] thermonuclear shot designated as BRAVO, was fired on a reef extending from the Island of Namu located on the northwest part of Bikini Atoll.

Figure 2 shows the estimate that I made of the pattern of fallout from BRAVO - expressed as the doses that persons who were out-of-doors, without shielding, could have received over a two day period following the initial

appearance of the fallout.

The doses shown over land areas were estimated from dose-rate readings by survey meters held at three feet above the ground. Doses over sea areas were extrapolations of land survey data and thus are much less certain. However, after constructing the "best fit" isodose lines, I calculated from these data that the total quantity of radioactivity that was deposited within 400 miles downwind represented about 2/3 of the total amount produced by the detonation. This estimate is not in conflict with those made in subsequent years by others who were able to incorporate more data from later surface detonations. In addition to the "absolute" values shown in Fig. 2, the relatively sharp gradients of the isodose lines, especially those across the main line of the fallout, are of interest to those concerned with the subject of this symposium. Of course, patterns of fallout will be strongly a function of the wind structure.

Figure 3 shows the estimated exposure rate readings on D + 1 day based on monitoring data made by personnel on the ground two to four days after the detonation.[2] The usual factor of time$^{-1.2}$ was used to convert these data to exposure rate readings at D + 1 day and to the two day out-of-door doses shown in Figure 2. The validity of using this conversion factor may be estimated by noting the exposure rate readings taken on the Island of Rongelap (Figure 4).[2] There was essentially no rain on this island for about two weeks after the detonation and the winds were light. At the end of the second week after the detonation a heavy tropical storm occurred. This could account for the observed exposure rate readings after the 10th day being lower than those anticipated by the time$^{-1.2}$relationship. Of course, there is no assurance that the exposure rate readings followed the straight solid line drawn between the 2nd and 10th days. It can only be inferred that any deviation would not be of major significance in terms of using the data in arriving at decisions for protective actions. As would be anticipated, the observed exposure rates deviate most from the time$^{-1.2}$ relationship at longer periods after the initial deposition - but these would be less crucial times. That is, the radiation exposure rates would be considerably less than at early times and more time would be available to evaluate the situation, make decisions and take action.

In brief, this was the pattern of fallout after the BRAVO event. What decisions were made and on what bases, how were the decisions carried out and what were the results of these actions?

Command personnel were aboard ships standing off Bikini Atoll at shot time. Some fallout did occur on these ships but by maneuvering the ships and by having the personnel remain below deck for a few hours the total dose was minimized. For example, my film badge later showed 150 milliroentgens.

By the time of our return to home base on Perry Island, Eniwetok, the radiation data on the northern island of Bikini had been obtained from automatic recorders and showed values up to the thousands of roentgens per hour at time of fallout. These were not unexpected values for the distances and times involved. It is to be recalled that until 1954 one school of thought held that high yield surface detonations would create intense fallout only in the immediate area of the shot and that most of the activity would be carried into the stratosphere where it would be scattered widely around the world. March 1, 1954 saw the dismissal of that school - permanently.

As had been planned previous to the detonation, an aerial survey was made at H + 31 hours over Rongelap Island, 115 statute miles to the east of ground zero. The reported radiation levels were about 4.0 roentgens per hour (extrapolated to ground level). The aerial reading subsequently was shown to be somewhat high, yet it triggered a chain of actions that was desirable. Obviously, something had happened to the predicted fallout pattern - later it was learned that shifting winds had veered the pattern southward over Rongelap, Ailinginae Atoll, Rongerik Atoll and Utirik Atoll.

Although it had not been anticipated that evacuation would be required, plans for such an eventuality had been made - as they should have been in a good safety plan. Both aircraft and surface ships were dispatched to Rongelap and at about H + 51 hours, 16 Rongelapese were evacuated by air and 48 by surface ship. Their total whole body exposure was about 175 roentgens.[3] Although the radiation exposure levels on the Island of Sifo on Ailinginae Atoll were less than one-half those on Rongelap Island, 18 inhabitants of this island were also evacuated by ship at about H + 58 hours. They were all taken to the Island of Kwajalein and given the best medical care, and their needs amply supplied. They were moved to the Island of Ejit on Majuro Atoll in June 1954 and returned to their home islands on June 29, 1957. A full account of the initial medical findings are contained in reference 3. Subsequently, annual medical examinations have been made by Dr. Robert A. Conard and his associates at the Brookhaven National Laboratory and the results of this outstanding work are reported in reference 4.

By late in the evening of the second day after the BRAVO detonation, radiation reports had been received about the Island of Utirik - about 315 statute miles to the east. It was not as apparent that evacuation was essential as it was at Rongelap Island since the radiation levels were considerably less. There were cogent arguments against evacuation of the inhabitants: (a) the estimated radiation doses probably would not exceed 60 rads - even if they remained on the island for a lifetime (b) evacuation would involve a sizeable number of inhabitants (154) and would entail some degree of hazard and hardship and (c) since such action would not go unnoticed in worldwide discussions of nuclear weapons testing there should be an impelling safety reason to require evacuation.

Recognizing the validity of these arguments, the counterarguments were: (a) there were ships capable of removing the inhabitants from Utirik by the third day after shot day (b) it might be possible to save them 45 roentgens of exposure by doing so and (c) the major decision, in terms of public relations, had already been made when the first Rongelapese and Ailinginaese were evacuated.

A decision was reached and evacuation of the 154 inhabitants of Utirik was started at about H + 55 hours and completed on H + 78 hours. They were also transported to Kwajalein where they were given the same care as those from Rongelap and Ailinginae and were returned to their home island of Utirik on June 5, 1954.*

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* Twenty-eight members of the Task Group conducting the nuclear tests were evacuated from Rongerik Island at H + 28.5 and H + 34 hours. Their total external gamma dose was estimated to be 78 rads.[3] It was later reported by the Japanese that some fishermen aboard a vessel near the Pacific Proving Ground may have received higher exposures than the Marshallese.[5]

In a retelling of this story more than a decade later the situation may appear so clear that the decisions should not have been difficult. However, like any emergency situation there are always uncertainties in the immediately available information. This was especially so since the initial radiation levels were estimated by conducting an aerial survey which was a technique not yet developed to its present reliable state. Also, as has been mentioned, at the time of BRAVO shot there was not indisputable proof that land surface bursts of high yield would produce such a heavy fallout at distances of a hundred miles and more, thus adding to suspicion of the initial aerial survey reports. Also, the energy yield of the detonation was twice that anticipated.[6]

Despite the best laid plans there always can be some element of risk and hardship in taking action under emergency conditions. However, the decision to conduct the first evacuation from Rongelap and Sifo Islands was easier than the second from Utirik, for here there were many more inhabitants who would be subjected to potential risk and hardship. Also, their maximum estimated lifetime radiation dose was 60 rads - an amount then equivalent to the maximum permissible over only a five-year period for atomic energy workers. Later, when these matters were discussed in the United Nations Trusteeship Council it was a favorable point to show that evacuation had been ordered. But suppose there had been unfortunate accidents during the evacuation - perhaps deaths. Would the decision to evacuate have been judged as wise?

There was not, however, a single casualty or injury during any of the evacuations. The well-laid safety plans and their efficient implementation paid rich dividends. But it should be pointed out quickly that these factors were abetted by two conditions (a) there were abundant capabilities at hand - aircraft, ships, equipment, trained personnel, etc. - and (b) the inhabitants were unaware of the potential hazard and were very cooperative. If there were a large and less amiable population, imbued with fear, rightly or wrongly, and there were only limited capabilities at hand for protective action - as might prevail under the conditions suggested for this symposium of a nuclear mass disaster - then there could be a different result.

This is all the more reason to proceed as far as possible now in the developing of practical radiation protection guides that can be synthesized into overall disaster plans and to conduct active programs of public education.

The St. George, Utah Incident

On May 19, 1953 a 32 kiloton nuclear shot, designated as HARRY, was fired on top of a 300 foot tover at the Nevada Test Site.[1]

Figure 5 shows the estimated doses that could have accrued if persons were present and remained for a lifetime at a given location. Most of the area shown is uninhabited - that was one of the principal reasons for selecting the testing site in southern Nevada. The original site was 640 square miles. Later this was expanded to about 1350 square miles. In addition, there is an adjacent area of about 4700 square miles that is controlled.

The highest estimated dose from this fallout was about five rads (again based on the assumption of continued occupancy of the area) to two

persons at a nearby ranch.[7] In terms of number of persons involved, St. George, Utah was affected most from the fallout from HARRY shot and it is that story that will be retold.

For every nuclear detonation an Advisory Panel was convened with experts in many fields, such as meteorology, nuclear medicine, health physics and public health, as well as those especially qualified in the study of fallout predictions. Prior to May 19, 1953, the Panel had waited patiently for 72 hours until the prediction of fallout was in an acceptable sector - toward the northeast.

At the weather briefing on the evening of May 18, 1953, the predictions were encouraging enough to keep the shot on schedule for the next morning. As the long hours droned on during the night there were frequent formal and informal briefings, as the Air-Weather Service Unit constantly collected and evaluated new data. With continued favorable reports and with the zero hour approaching, decisions had to be made.

Mobile monitoring teams had been dispatched during the day and were in the general vicinity of their assigned locations. It was now necessary to spot them more definitely. Also, at about this time it was customary for the Liaison Officer of the Federal Aviation Agency, attached to the Test Organization at the Nevada Test Site, to direct the closure of certain air spaces for commercial aircraft from the Site out to specified distances, altitudes and times, principally to avoid the possibility of the flash of the detonation temporarily dazzling the eyes of pilots. Cloud tracker aircraft of the Test Organization were ordered to take off so as to be in position at H-Hour. Helicopter crews were alerted for close-in terrain surveys and L-20 and C-47 crews for more distant terrain surveys. The usual ground and aerial sweeps had been made in the afternoon to assure there was no unauthorized person in the close-in areas in the direction of the fallout. The technical crews reported their readiness for all experimental work on-site and off-site.

At 0505 Pacific Daylight time, on the morning of May 19, 1953, HARRY was detonated. Within a short time the initial technical data from HARRY shot was collected and most of the scientists went back to camp for a well earned rest. But not the radiological safety personnel - their day was just beginning.

The first on-site and off-site reports were encouraging. The fallout was progressing to the east-northeast and crossed Highway 93 south of Alamo and north of Glendale, Nevada as predicted. In anticipation of this event, roadblocks had been established on Highway 93 at Alamo at 0715, and at Glendale at 0725. This prevented persons being directly in the fallout as it occurred, thus reducing the whole body exposure and the possibility of direct contamination of personnel and equipment. The roadblocks were removed at 0851 and the cars monitored after they had traveled through the area. Precautionary closing of Highway 91-93 between Las Vegas and Glendale had been ordered at 0735 and lifted at 0805. A precautionary roadblock had been established at St. George at 0745 but it was not until 1130 hours that this roadblock was lifted. All in all, hundreds of cars were monitored and about 40-50 vehicles were washed (at Government expense) according to the established radiological safety criteria.

Groom Mine was not directly in the path of the predicted fallout but since it was the nearest inhabited place - about 30 miles from ground zero - monitors were stationed there. At 0632 the radiation level rose rapidly to 140 milliroentgens per hour and the few inhabitants living there were asked to remain indoors. They were released at 0748 after the cloud had passed and the levels had subsided. At 0920 the radiation levels outside were 11 mr per hour and were dropping rapidly. Incidentally, there were other occasions when individuals or families located near the test site were temporarily relocated. Usually this involved from one to a dozen or so persons who were taken to one of the surrounding communities of their choosing, like Las Vegas, on the day before a detonation. They were paid a stipend by the day and were returned to their homesites as soon as cleared by radiological safety officers.

The trajectory of the air mass containing the radioactive debris passed south of Groom Mine, moved in an east-northeasterly direction, and crossed Highway 93, south of Alamo - all about as predicted. The monitoring data suggested that the pattern was somewhat farther south than predicted, but not disturbingly so. Beyond Highway 93 and in the line of the trajectory lay uninhabited country for many miles. Everything looked in good shape.

The monitors at the St. George roadblock (actually at the junction of Highways 91 and 18 to the west of St. George) noted that at 0845 the background levels were increasing. By 0910 the levels had risen to 320 mr per hour and a quick check of an automatic background recorder at nearby Dixie College showed about the same reading. It was determined later, however, that the instruments had been contaminated by the fallout. When another nearby mobile team brought in clean instruments and a correction factor was applied, the value was 220 mr per hour.

Not relying solely on radio communications, Mr. Frank A. Butrico of the Public Health Service and head of the monitoring team had wisely called the Control Point at the Nevada Test Site by long distance telephone and was keeping Dr. Jack Clark of the Los Alamos Scientific Laboratory and me informed of the situation as it developed. As the radiation levels rose at St. George, we knew that they were exceeding predicted values at that point, yet they were well below hazardous amounts. It was more of a question of precisely how much higher might the radiation levels rise and how long would it require to take protective actions.

We decided to ask the residents of St. George to stay indoors, which they did from about 0930 to 1130 at which time they were released. Later, the lifetime exposure at St. George was estimated to be about 2.5 rads from this fallout.[7] In retrospect, and please be assured that evaluating in retrospect is much easier than prospect, it would appear that a large fraction of the potential whole body dose was not eliminated by this evasive action. Remaining indoors did minimize direct body contamination and inhalation of radioactive debris during the period of time that it was falling to the ground and it did provide a somewhat more controlled situation in the event further action was deemed essential.

Again, the decision and action sound simple. However, there were about 4500 persons involved, spread through the city. Hundreds of children were at school. Cars and trucks were moving about the city on their normal business. This would be the first time that action would be taken with such a large community and on short notice. Instructions to evacuate immediately might induce a panic with its attendant hazards and would, in fact,

bring many persons out of their homes, schools, and offices into the open during the time when the fallout was occurring most abundantly. We might actually do more harm than good, yet if action were needed it should come quickly to be fully effective. But was any emergency action really imperative or what action was best when evaluated against potential risks? These are the conflicts of arguments that decision-makers must cope with, often under trying emotional conditions, and under the pressure of time.

As Mr. Butrico reported later, "At 0925 instructions were received to have the people in St. George take cover. The Sheriff was notified and he in turn contacted the radio station in Cedar City to get the announcement over the air. In addition, the school principals were notified of the situation so that the children would not be sent out into the open during recess periods. At 0940 the bulk of the population in the city of St. George was under cover. The effectiveness of the operation was amazing."

More lies behind this statement than is apparent. The radiological safety group had conducted orientation sessions with the local officials and to a lesser extent with the general public at St. George and other communities. Although the officials might not have thoroughly understood all of the science involved they were aware of the potential problems. Most important, a line of communication had been established so that no time was lost when a decision was made to act.

Another key factor was that orders to remain indoors came from a recognized officer of the law and a local man whom everyone knew and trusted - the orders did not come from a stranger dressed in white coveralls, with a Martian face mask, and a queer "ray instrument" in each hand. (This description is for purposes of illustration - the monitors did not actually dress in this manner.) Thus the populace accepted the order readily, obeyed quickly, and did so without panic or accidents.

At the time of the orientation sessions and formulation of safety plans, no one could clearly foresee exactly what emergencies might arise nor precisely what action might be called for. Yet the basic requirements of understanding and communications were established. These were all that were needed in this situation. Much more extensive plans and capabilities could be required in other situations. In any event, education of officials, especially those who are in positions of authority to order actions be taken, and of the public is one of the basic requirements of any good safety plan.

The Salt Lake City Incident

A nuclear device was detonated on or near the ground on July 7, 11, 14 and on 17, 1962, at the Nevada Test Site. A cratering shot also was fired on July 6, 1962 at the Site.

With increased alertness to possible environmental contamination and with monitoring methods that had been perfected in recent years which permitted rapid measurements of a large number of samples, the rise of iodine-131 levels in milk in the Salt Lake City environs was followed closely. As the levels rose from nondetectable amounts in early July to peak amounts on July 25, apprehension increased among the officials and residents of Salt Lake City, located about 350 miles northeast of the Nevada Test Site. It was understood by them that the (U.S.) Federal Radiation Council's Radiation Protection Guide was 36,500 picocuries of iodine-131 that might be ingested in any one year.[8] By the end of July the total ingested (based

on usual assumptions and calculations) had risen to 27,000 picocuries. Although the amounts of iodine-131 per liter of milk were decreasing by then, the accumulated intake continued to increase, of course, toward the assumed "end point" of 36,500 picocuries. (The final tally was 37,040 picocuries).[9.]

The press and others brought strong pressures to bear on the public officials to take action for they had come to understand the "limit" to be the 36,500 picocuries. The state and city health authorities met with representatives of the milk industry; as a consequence several actions were taken by the latter in early August. Of the 759 milk producers in the Salt Lake City area, 285 placed their cows on dry feed, 211 others diverted their milk into milk products. This represented 53,000 gallons of the 77,000 gallon total daily milk production.[9.]

Obviously, these were not minimal actions. Two-thirds of the producers were affected, representing two-thirds of the milk supply for Salt Lake City. The public was upset and worried. Some families switched to powdered milk, and others eliminated milk from the diet of children.

On August 17, 1962, the U. S. Public Health Service released a statement, "The Utah action was based upon the radiation exposure guidelines recommended by the Federal Radiation Council and accepted by the President last September."[10.]

Yet, on August 29, 1962, the Federal Radiation Council stated in a letter to the Joint Committee on Atomic Energy (Congress of the United States): "The Council recognizes that premature action has been taken in some areas to reduce the intake of iodine-131 which action the Council would not have recommended under its interpretation of the guides..."[11.] The exchange of letters between the Federal Radiation Council and the Joint Committee on Atomic Energy led to such newspaper headlines as "States Chided for Acting Too Soon Against Radiation Threat in Milk."[12.]

Much further discussion could be reported (references 13 and 14) about this incident - who said what to whom and when and why - but this is sufficient to illustrate how an unfortunate situation can arise if there are not clear understandings of the radiation protection guides and their appropriate application.

In a letter of August 17, 1962, from the (U.S.) Federal Radiation Council to the Joint Congressional Committee on Atomic Energy, it stated that the radiation protection guides, "... are not intended to set a line at which protective action should be taken or to indicate what kind of action should be taken." Yet without this advice, the guides were misinterpreted to mean a "limit", a "maximum", a "danger level." (In July 1964, the Federal Radiation Council did recommend Protection Action Guides that were appropriate for taking countermeasures.)[15.]

On August 7, 1962, at the height of the scare in Salt Lake City, members of the U. S. Public Health Service and I met with officials in Salt Lake City. Later there was a discussion with the press and an interview on the local television station. It is to the credit of the citizens and the press of the Salt Lake City area that when proper interpretations were given of the Federal Radiation Council's guides, the local press reported that, "The scare over the content of radioactive iodine (I-131) in Utah milk subsided ...".[16.]

Such an occurrence, however, can leave a regrettable imprint. It is

difficult enough to educate the public correctly without compounding the problem ourselves.

There is an addendum to this story.

Because of the increased interest in iodine-131 that this incident created, many attempts have been made to estimate the amount of iodine-131 in milk during past atmospheric tests based on such measurements as external gamma readings, concentrations of total beta activity in air and gross beta activity on gummed paper. All of these paper studies suffer such severe uncertainties as to seriously question their usefulness.

For example, local fallout patterns can have sharp gradients as illustrated in Figure 5. I have measured external gamma radiation levels in local fallout patterns that have varied one from the other by factors of 5 to 10, all within a few hundred meters. More than one paper study has been done using past monitoring data and attempting to establish correlations between external gamma readings and the amount of iodine-131 in milk. I recall one meticulously prepared study.[17] The mathematics was elegant. The only trouble was that the author had not determined, for example, that the external gamma readings he used were taken by monitors outside of a bar within the town while the pasture land was miles down the road. The monitors were not derelict in their duty since their first obligation was to assure safety of persons at the time of the fallout and they went to the places where people were located.

There was a carefully documented test[18] performed after some leakage occurred following an underground nuclear detonation on March 13, 1964, at the Nevada Test Site. It showed that the amount of iodine-131 deposited on one farm about 70 miles from the test site differed from another by factors of two to five even though the farms were within five miles of each other in a broad valley with no significant topographical features separating them. In fact, the amounts of deposited iodine-131 at two places only 200 yards apart on a farm differed by a factor of seven.

To attempt to estimate quantitatively the amount of iodine-131 in milk by measurement of external gamma readings incorporates not only the uncertainties just mentioned but also adds those due to possible (a) fractionation of the fission product debris (b) incorporation of varying amounts of induced activities in the fallout (c) wide variances of retention of the debris on the foliage (as a function of particle size distribution and other factors) and (d) other variables such as accurate instrument response, especially at relatively low exposure rates (where most studies have been performed) and extrapolation of external gamma readings by the time$^{-1.2}$ relationship. All of these leave one with an uneasy feeling of confidence in the conclusions. The most gross relationship might be inferred in comparing different types of data such as external gamma levels and iodine-131 in milk but then only as an alert for possible additional monitoring. In fact, as stated in the report[18] on the study made following the March 13, 1964 event, "... the external beta plus gamma measurements were background throughout the study ... utilizing such relationship in this instance would have led to the conclusion that there would have been no measurable I-131 milk levels found whereas our data indicate that levels could actually have reached values near 700 pc/l had the study been started at an optimum time." (The highest measured value was 420 picocuries per liter.)

Even less can be said for using concentrations of radioactivity in the air as the basis for a model to predict quantitatively the amount of iodine-131 in milk. One analysis[19] of extensive monitoring data concluded, "The air network, which should act as an 'early warning' system, to warn us of approaching radioactive contamination, is of very limited value, if not misleading. The air network failed to give warning of high iodine-131 levels in milk in most places in the U. S. last fall." (fall of 1961).

Paper studies have been made[20] purporting to predict within a factor of two the dose to the thyroid based on estimated iodine-131 in milk, which in turn are based on gross total beta activity collected on gummed paper. Most of the uncertainties already mentioned and probably additional ones apply to this method of prediction.

In brief, monitoring procedures, equipment and data, if properly employed, are useful for the purpose for which they are intended. To extrapolate or reinterpret them into other forms of information is done so at a considerable risk of authenticity.

It is recognized that some think more highly of these paper studies made to predict the iodine-131 content in milk from other data, but I believe there would be agreement on one point. If it is deemed essential to determine the iodine-131 content in milk then a good safety plan should provide for its direct and early measurement. The same assertion applies to all other key radiological data.

One final story. Even with the best laid plans and with a superior organization to carry them out, things can still go awry.

Following a cratering experiment using an underground nuclear explosive at the Nevada Test Site in the spring of 1965 some radioactivity contaminated pasture lands to the north of the site. As planned, radiological monitors went into immediate action. Among the many surveillance activities conducted was the daily collection of milk from the affected farms. In the midst of these daily collections, I received word by telephone that one of the cows had died. This was most difficult to explain since the measured levels of activities, both external gamma and iodine-131 in milk, were very low. An investigation revealed that samples of milk were sent from the farms to the laboratory on daily basis. On this particular day no sample of milk was received from one farm but instead the monitor had written a note stating that the cow had "kicked the bucket" - which also is a slang phrase meaning someone has died. Further investigation verified that indeed she had literally kicked over the bucket and that was why there was no milk sample from that cow for that one day.

ACKNOWLEDGMENT

Acknowledgment is gratefully made to Mr. Robert E. Allen, Dr. Roy D. Maxwell and Mr. Tommy F. McCraw of the Division of Operational Safety, U. S. Atomic Energy Commission, for their assistance in the preparation of this paper.

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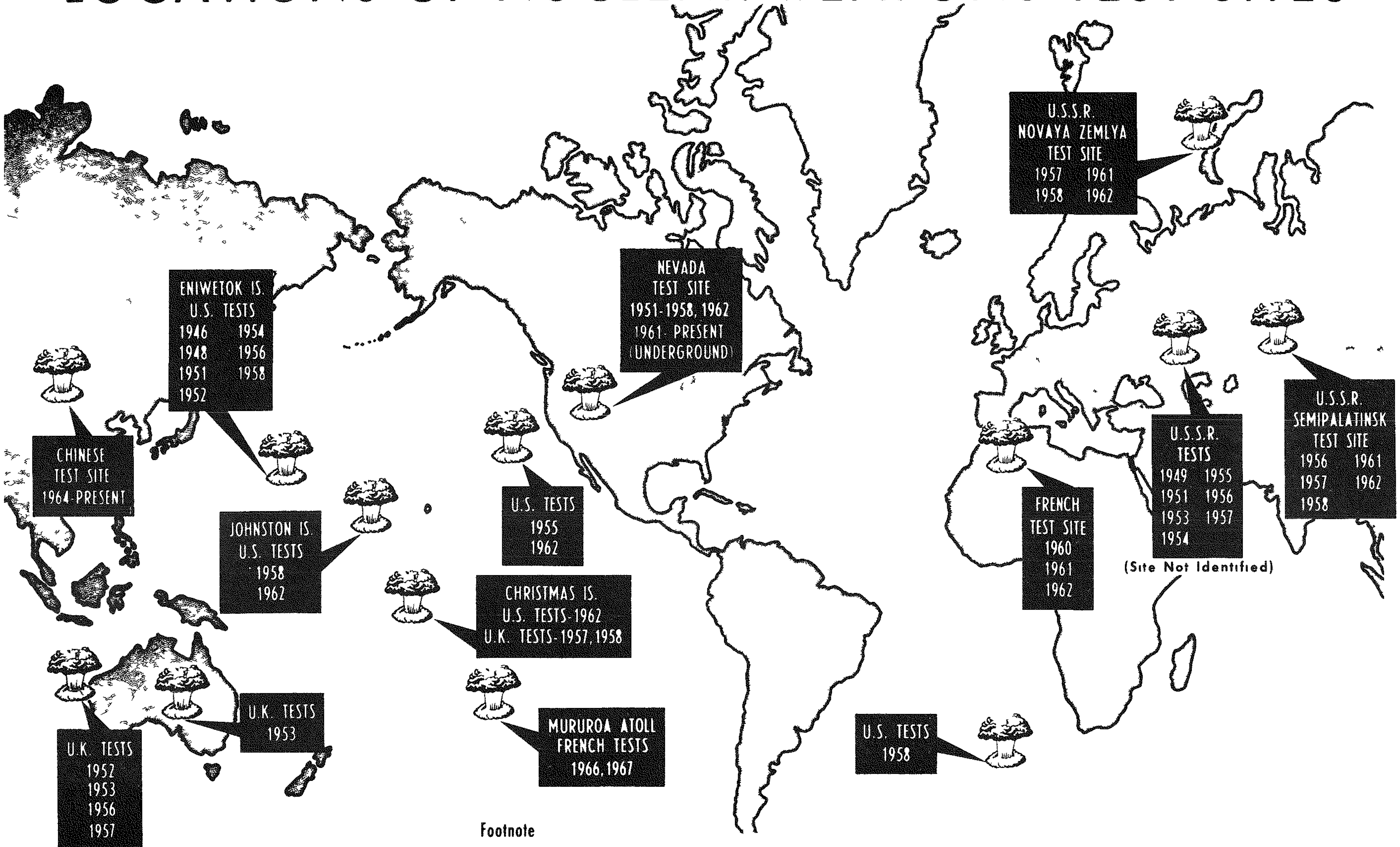
Figure 1

LOCATIONS OF NUCLEAR WEAPONS TEST SITES

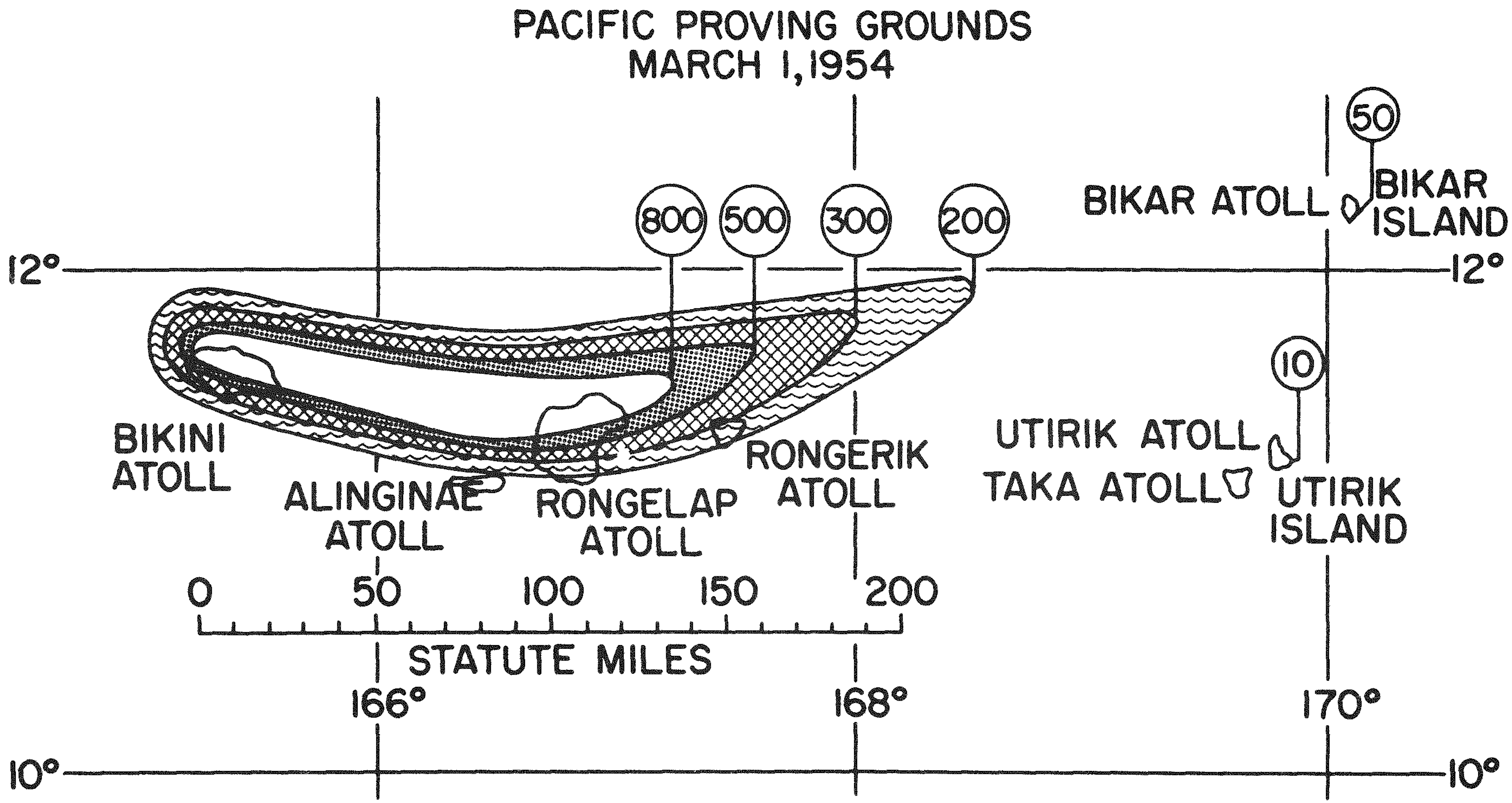


Footnote

UNDERGROUND NUCLEAR DETONATIONS WERE CONDUCTED NEAR CARLSBAD NEW MEXICO 1961 NEAR FALLON NEVADA 1963 NEAR HATTIESBURG MISSISSIPPI 1964 AND 1966 AMCHITKA ISLAND ALASKA 1965 NEAR FARMINGTON NEW MEXICO 1967 AND HOT CREEK VALLEY NEVADA 1968
U S S R UNDERGROUND TESTS SINCE 1963 NOT INCLUDED

Figure 2

ISODOSE CONTOURS



The numbers on the above map represent the doses that would have been received over approximately 48 hours without shielding. The dose, above which survival is unlikely, is 800 r and below which survival is probable is 200 r.

411

Figure 3

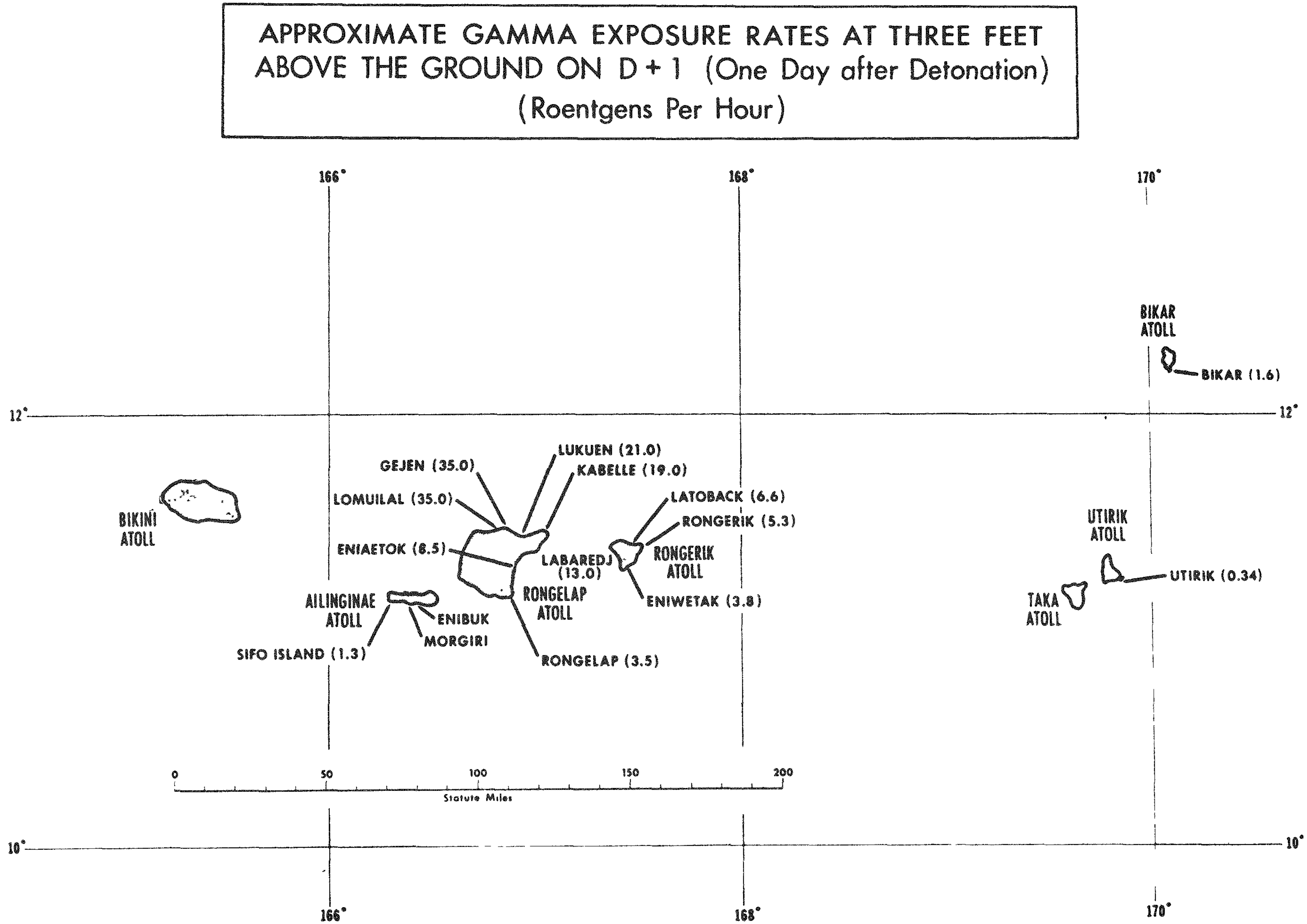

APPROXIMATE GAMMA EXPOSURE RATES AT THREE FEET ABOVE THE GROUND ON D + 1 (One Day after Detonation)
(Roentgens Per Hour)
166°
168°
170°
12°
10°
BIKAR ATOLL
BIKAR (1.6)
BIKINI ATOLL
GEJEN (35.0)
LUKUEN (21.0)
KABELLE (19.0)
LOMUILAL (35.0)
ENIAETOK (8.5)
LABAREDJ (13.0)
RONGELAP ATOLL
RONGELAP (3.5)
LATOBACK (6.6)
RONGERIK (5.3)
RONGERIK ATOLL
ENIWETAK (3.8)
AILINGINAE ATOLL
ENIBUK
MORGIRI
SIFO ISLAND (1.3)
UTIRIK ATOLL
UTIRIK (0.34)
TAKA ATOLL
0
50
100
150
200
Statute Miles

Figure 4

GAMMA EXPOSURE RATES ON THE ISLAND OF RONGELAP

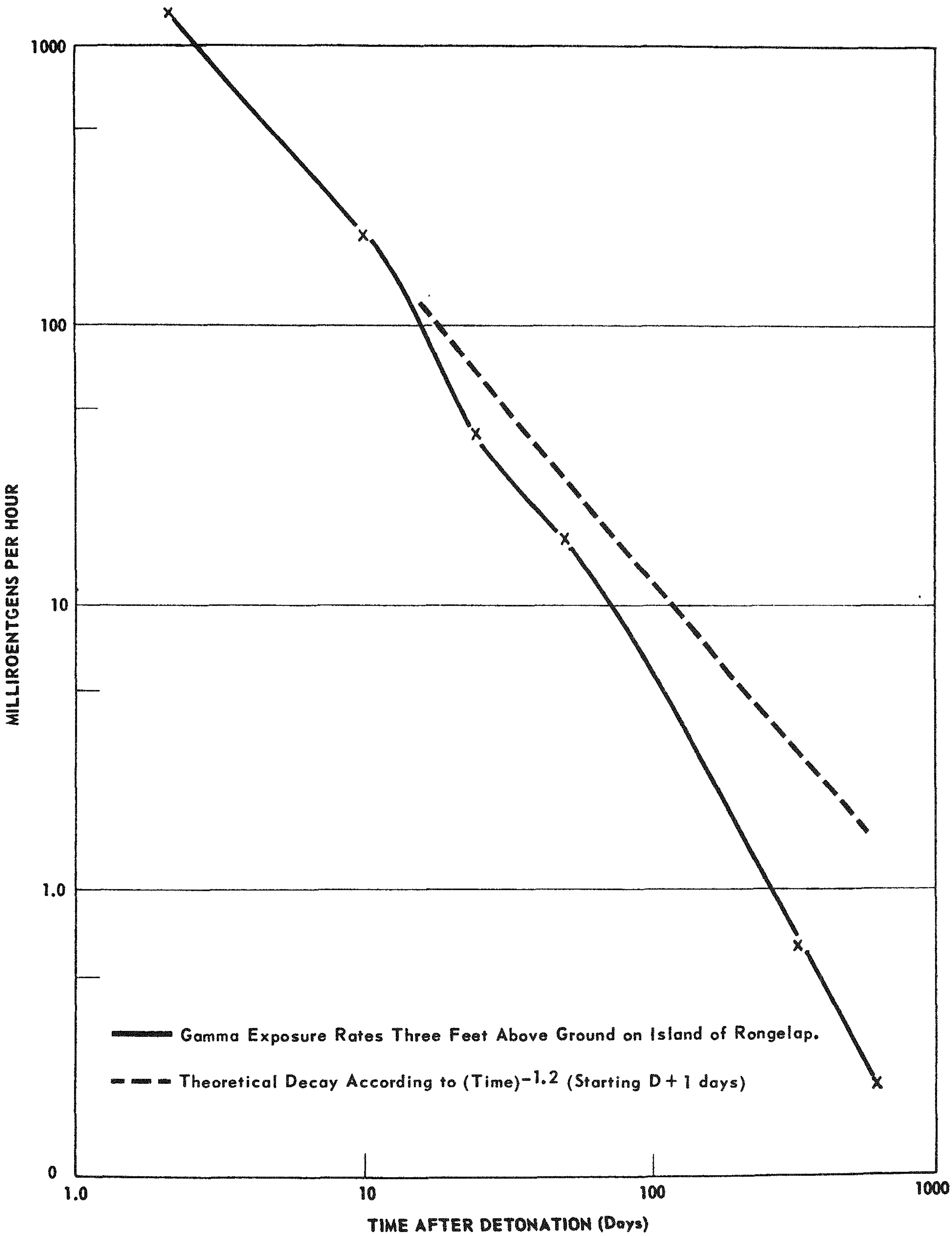
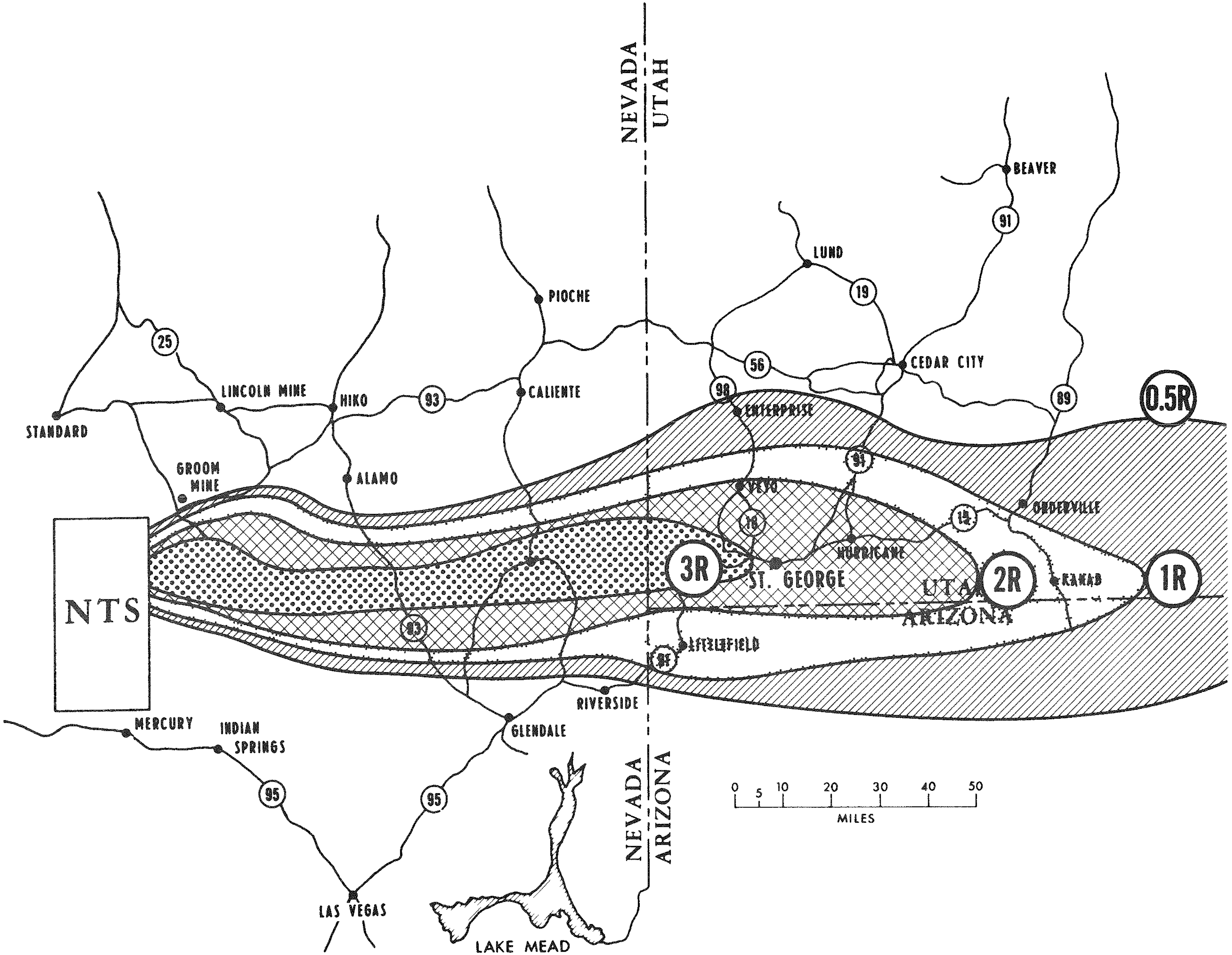


Figure 5

ESTIMATED EXPOSURES FOLLOWING HARRY SHOT MAY 19, 1953



The Spanish Incident

I have been asked to speak about the incident in Spain where plutonium was released from two nuclear bombs and contaminated the immediate area. In this instance I can only act as a reporter but here in brief are the data.

On January 17, 1966, a B-52 U.S. Air Force aircraft with nuclear bombs aboard crashed in Spain following an accident during a refueling mission. One bomb was soon found in the soft soil of a river bed and one was found in the Mediterranean after an extensive search. Two other bombs were shattered by their conventional high explosives upon impact on land and in doing so scattered their contents over the local area. It was, in fact, an exact performance expected in case of an accident with nuclear bombs, i.e. they are designed so that in the event of an accident only their conventional high explosive will detonate. Of course, the radioactive contents of plutonium and uranium were physically scattered, like any other debris, but there was no nuclear reaction.

The obvious question remains, what was the health hazard from the plutonium and uranium that was scattered in the environment?

Plutonium constitutes the greater potential hazard of the two so that only this isotope will be considered. When plutonium reaches the air it quickly oxidizes forming insoluble plutonium oxide, or if it dissolves in water, it forms an insoluble hydroxide. Thus, any plutonium taken into the body by inhalation or ingestion will not be absorbed to any appreciable extent. This is fortunate since plutonium has a long half-life of about 24,000 years and if it reaches the bones will be eliminated only very slowly. On the other hand, any insoluble plutonium oxide inhaled into the lungs will be eliminated with a half time of about one year, i.e., one-half of any plutonium remaining in the lungs will be removed by natural body processes in the following year. The plutonium will be moved up from the lung, swallowed, and then it will pass quickly through the body - in a day or so - and be eliminated. This leaves one principal worry - what will be the radiation dose to the lungs before the plutonium is eliminated from that organ?

But first, let us take a look at what happened in Spain.

One bomb landed near the village of Palomares - in fact so close that one man was knocked backwards through the doorway of his home by the blast wave from the high explosive. He was uninjured. The other bomb fell in an uninhabited place and at a sufficient distance from the first so there was very little overlapping of the patterns of contamination.

The potential sources of inhalation of plutonium under these conditions are one, the cloud of radioactive material as it rolls by immediately after the event and, two, resuspension of the plutonium from the ground into the air afterwards. Available data indicate that the first source will probably result in a higher amount of plutonium being deposited in the lungs.[1] Obviously there were no personnel monitors or equipment present at Palomares at the time of the accident, so what assurances can be given as to the degree of risk to the inhabitants?

As these types of nuclear weapons were being developed it was, of course, realized that just such an incident as happened near Palomares could occur. First, the nuclear weapons were designed so that only the high explosive would detonate. Second, extensive experiments were conducted, including two

major field tests,[1., 2.] that showed the amount of plutonium that might be inhaled in the event of such an accident.

In short, these experiments showed that if a person were exposed to the highest concentration of plutonium in the cloud from such an accident he might receive a total radiation dose to the lungs of about 5 to 10 rem. The second of the major field tests was conducted under inversion meteorological conditions in order to maximize the concentration in the air at ground level. To evaluate such a potential dose it may be recalled that the safety standard for the lungs of atomic energy workers is 12-15 rem <u>each year</u>.

As stated, any radiation exposure to the lungs as a result of resuspension of the plutonium from the ground (except possibly in the immediate impact area) probably would be less than that from passage of the cloud. In this case, however, it was possible and feasible to remove much of the plutonium from the environment by simply scraping off the soil to a depth of two to three inches. This action was taken over some 5-1/2 acres of land (0.022 square kilometers) resulting in 1100 cubic yards (283 cubic meters) of soil that was transported to the U.S. Atomic Energy Commission's Savannah River plant, near Aiken, South Carolina, and buried on April 14, 1966 in the same manner as other low-level radioactive waste material. Also removed from the site of the accident and buried at the U.S. Atomic Energy Commission site were about 400 cubic yards (100 cubic meters) of vegetation. Once again, the situation was one of only surface contamination of the vegetation, i.e., plutonium oxide is quite insoluble so that very little finds its way from the soil into the roots of plants. It was planned to deep plow some 300 acres having low but disernible amounts of contamination but the operation was found to be so easily performed that the area was extended to a total of about 600 acres (2.4 square kilometers). This process reduced the surface contamination to undetectable amounts and essentially eliminated any resuspension of plutonium into the air. This information is summarized in the following table.

<u>Approximate Levels and Areas of</u>
<u>Plutonium Contamination</u>

(total for both areas contaminated)

Counts per minute	Areas in square kilometers	Actions Taken
zero *	2.4	Deep plowed and water
700	2.0	(Deep plowed, (watered and
7,000	0.17	(vegetation removed
over 60,000	0.022	Surface scraped

* not detectable

All of this information on the Palomares incident is subject to correction by those who have firsthand knowledge.

Since available data indicate that more plutonium probably would be inhaled during passage of the cloud than by the process of resuspension, and the former may result in only a 5 to 10 rem dose to the lungs, there may be some discussion on how extensive should be the clean-up or decon-

tamination efforts. Probably the answer lies in the feasibility of those efforts. In time of a "nuclear mass disaster" decontamination measures solely for plutonium probably would not have first priority. At other times it is a question of valued judgment - what is operationally feasible and what is acceptable in terms of public reactions?

In any event it is comforting to know the data indicate that following the scattering of the plutonium from a bomb the potential dose to the lungs would not be large and that the dose due to resuspension probably would be less even if decontamination measures are not instituted.

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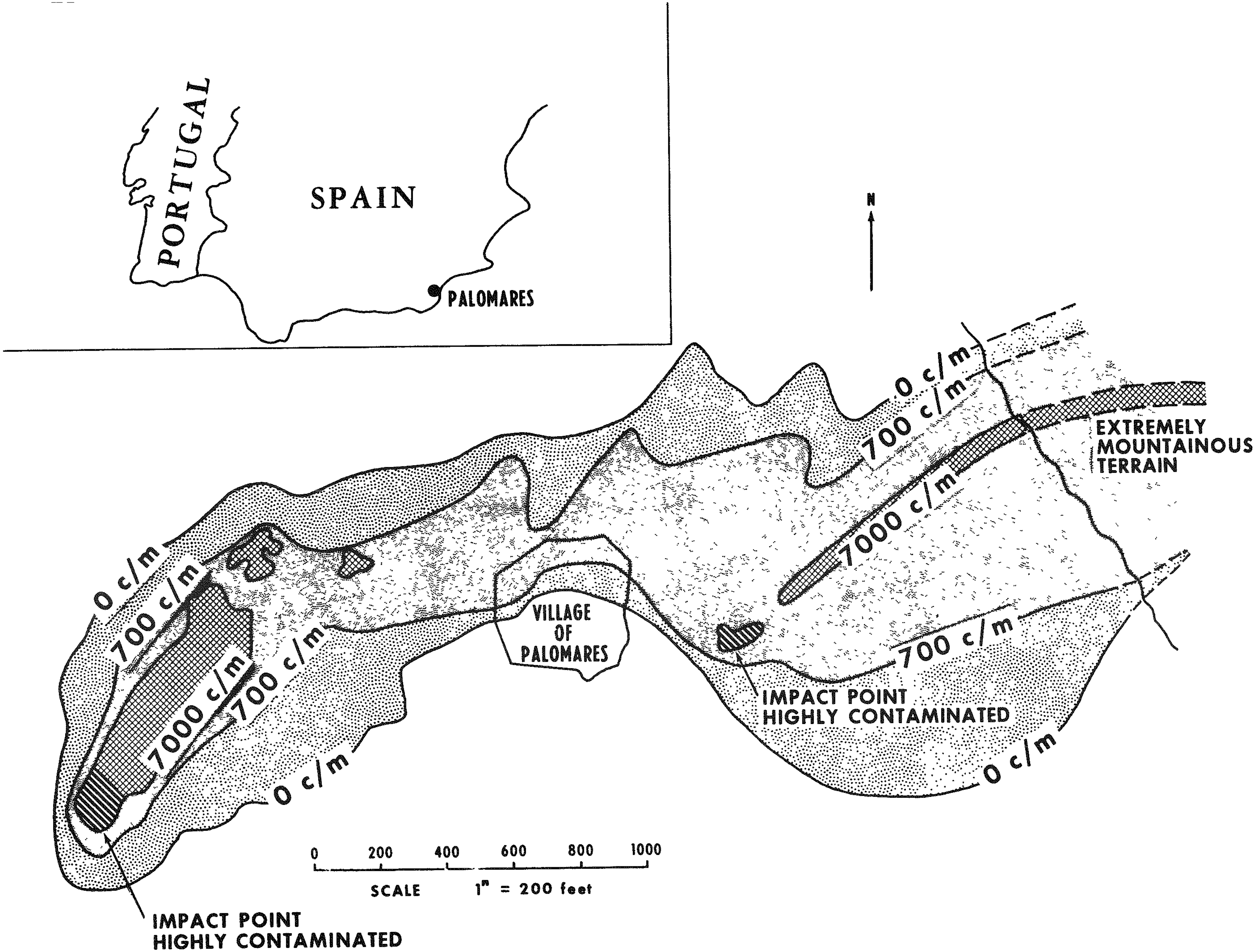
PORTUGAL
SPAIN
PALOMARES
N
0 c/m
700 c/m
7000 c/m
EXTREMELY
MOUNTAINOUS
TERRAIN
VILLAGE
OF
PALOMARES
IMPACT POINT
HIGHLY CONTAMINATED
0 200 400 600 800 1000
SCALE 1" = 200 feet

BNWL-SA-1509

POST ATTACK ACTIONS IN A NUCLEAR MASS DISASTER[a]

5.4

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2

Survival and rehabilitation following an all-out nuclear war will depend to a great extent on preparations that have been made in advance for coping with such an event. During this advanced planning period, civil defense leaders must face up to realities and acknowledge that such a nuclear mass disaster could occur. Advance preparations should include, as a minimum, (1) the construction of shelters stocked with ample supplies of food, water, medicine and other necessities; (2) a means of communication between civil defense authorities and the people, both to alert them to take shelter and to keep them informed of conditions while they are in shelters; (3) a system for determining the dose rates from the fallout at various locations throughout the city or community; and (4) a designation of lines of authority for the post-attack period. All these actions must be made prior to the arrival of the fallout.

Assuming that these basic preparations have been made and that the population has been alerted in time to reach shelters; many near ground zero, even some in well constructed and stocked shelters, will be lost. However, the majority of those who have reached shelter, especially those further from ground zero, will survive to be later confronted with the real problem of decontamination and recovery of their home and community. Radioactive debris may have fallen all around them. Dose rates, possibly measuring thousands of R/hour, using H + 1 hour as reference, may emanate from a layer of fine dust, some of which will have drifted into houses, hospitals, factories, stores, schools - everywhere. To venture outside for any length of time soon after the arrival of such radioactive fallout could be fatal. Inside the shelter there is safety and protection; however, sooner or later people must emerge from their shelter and contribute their share to the total effort required for rehabilitation of the community and country. Those who found it prudent to take cover in residential buildings, stores or basements rather than in a fallout shelter will be afforded some protection, but to a much lesser degree than those in shelters. Figure 1 shows the relative protection afforded at different locations within a typical residential structure.

Let's review possible post-attack actions of a family who took refuge in a fallout shelter located in the basement of their home. Let's assume the shelter, located a few miles downwind from ground zero of a rather large nuclear detonation, had an ample supply of the essential items including a battery operated radio, but that no provisions had been made for a dose rate meter in the shelter. Thus, the occupants would have to rely on information concerning dose rates in their general neighborhood broadcast over radio networks. If we further assume unshielded H + 1 hour dose rates up to 6000 R/hour outside the shelter and a protection factor of 1000 for the shelter, it is apparent that occupants will receive sub-lethal exposure if they remain inside the shelter. Several days will elapse however, before conditions outside will warrant any exit from the shelter except for the most urgent reasons.

DOSE RATES AND PURSUITS THAT CAN BE UNDERTAKEN FOLLOWING A NUCLEAR MASS DISASTER

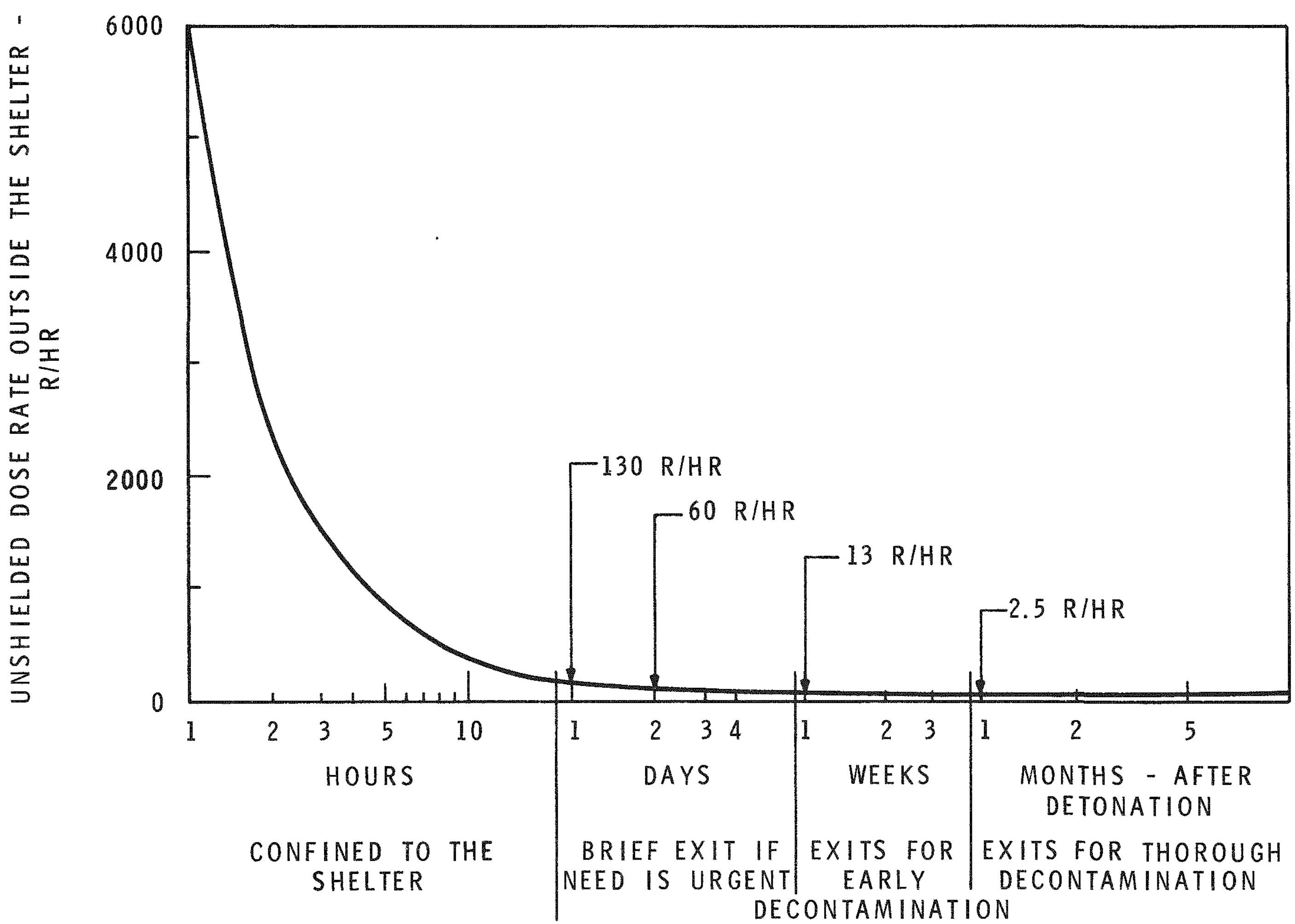

FIGURE 2
Dose Rates and Pursuits that Can be Undertaken Following a Nuclear Mass Disaster

RADIATION CONTRIBUTED TO EXPOSURE AT CENTER OF TYPICAL SHELTERS FROM VARIOUS SURFACES

	AVERAGE HOUSE		OFFICE BUILDING		WAREHOUSE	
TYPE OF SURFACE	1ST FLOOR	BASEMENT	1ST FLOOR	BASEMENT	1ST FLOOR	BASEMENT
ROOF	30%	60%	25%	40%	60%	80%
LAWNS	30%	15%	30%	24%	14%	5%
SIDEWALKS AND DRIVEWAYS	20%	10%	25%	20%	10%	3%
STREETS	12%	6%	10%	8%	5%	2%
OUTSIDE WALLS	4%	7%	10%	8%	10%	10%
TREES, FENCES, ETC.	4%	2%	---	---	1%	---
TOTAL	100%	100%	100%	100%	100%	100%

FIGURE 4

Radiation Contributed to Exposure at Center of Typical Shelters from Various Surfaces

PROCEDURE	EQUIPMENT	PERSONNEL	RATE (SQ FT/HR)	REDUCTION FACTOR
SCRAPING	1 MOTOR GRADER	1 OPERATOR	45,000	4-5
FIRE-HOSING (COMPOSITION ROOF)	1 WATER TRUCK	1 OPERATOR 2 HOSEMEN	3,000	2
FIRE-HOSING	1 WATER TRUCK	1 OPERATOR 2 HOSEMEN	4,000	2-3

FIGURE 5
Application and Effectiveness of Reclamation Procedures

L

DECONTAMINATION AS A REMEDIAL MEASURE

5.6

By

Carl F. Miller

INTRODUCTION

The utility of decontamination as a remedial measure to reduce exposure doses from fallout for a purpose may be examined in terms of selected (1) exposure dose parameters, (2) radiological defense (RADEF) countermeasure parameters, and (3) planning criteria for RADEF operations. The major exposure dose parameters include:[1]

1. an exposure rate decay curve,
2. the reference exposure rate or standard intensity, I_s,
3. the time of arrival and rate of fallout during the arrival period.

The major RADEF countermeasure parameters include:

1. the shelter shielding residual number, RN_1,*
2. the shelter stay or exit time, or the entry time to an outside radiation field, t_e,
3. the decontamination (or other) operational crew residual number, RN_2,
4. the effective long term decontamination and building shielding residual number, RN_3.

The major planning criteria for RADEF operations include:

1. an operational exposure dose limit, D^*,
2. the concept of time-phased RADEF systems,
3. the specification of alternative operational routines for use of the systems.

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1. Miller, C. F., H. Lee, and J. D. Sartor, Introduction to Radiological Defense Planning, SRI Project No. MU-5069, May 1965

* The residual number is the ratio of the exposure dose at a given location upon use of a countermeasure to that for a reference location (e.g., at 3 ft above a uniformly contaminated open land area).

The residual numbers are usually complex quantities as applied to a real RADEF system and include combined considerations of radiation source strengths and locations, attenuation by shielding materials and distance, exposure times, removal of sources by decontamination, movement of recipients, rearrangement of sources by weathering (where known), and definition of the reference locations.[2,3]

In many RADEF system studies for evaluating the effectiveness of proposed countermeasure components, it is convenient to consider only three broad categories of radiation injury for humans; these are:

1. Radiation injury from which recovery of all persons so exposed is virtually certain. The upper-limit exposure dose for this category used here is the equivalent of a maximum effective residual dose (ERD_{max}) of 200 roentgens.[4]

2. Radiation injury that results in death to virtually all persons so exposed. The lower-limit exposure dose for this category used here is 600 roentgens in four days or 1,000 roentgens in one month.

3. Radiation injury from which recovery is uncertain or unknown.

Since it is clearly the purpose of a planned RADEF system to maximize the number of people that would be in the first injury category, the main feasibility test of such a system is to determine whether the operational exposure limit, D^*, is equal to or less than the equivalent of 200 r, ERD_{max}. The values of D^* that approximate this limit, for an effective fallout arrival time of about one hour after detonation, are about 190 roentgens in one week, 270 roentgens in one month, and 700 roentgens in one year. The constraining equation for system feasibility is, in general, given by

$$D^* \geq RN_1D_1 + RN_2D_2 + RN_3D_3 \tag{1}$$

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2. Lee, Hong, Radiological Target Analysis Procedures, SRI Project No. MU-5069, March 1966

3. Lee, Hong, Decontamination Scheduling Procedures for RADEF Systems, SRI Project No. MU-5069, August 1966

4. National Committee on Radiation Protection and Measurements, Exposure to Radiation in an Emergency, Report No. 29, August 1962

where D_1 is the exposure dose at the reference location while people are in shelter, D_2 is the reference exposure dose during a decontamination operation, and D_3 is the reference exposure dose from the end of the operation to about 2.3 years later. The time-phasing of a RADEF system corresponding to Equation 1 is that the people represented occupy the shelter during the attack and transattack period of a nuclear war; some or all of the people come out of the shelter at an appropriate later time and decontaminate designated facilities or areas; and all people leave the shelter when the decontamination operation is completed and live in the area with no further constraints on their activities due to radiation exposure (provided feasibility is established). The basic routine for this RADEF system is to occupy shelters on warning and remain through the attack and transattack periods; organize and carry out decontamination of the surrounding facilities and areas as soon as possible; and leave shelter to restore normal activities in the area. Many other more complicated alternative routines or variations to this simple routine can be developed but the simple routine is sufficient to illustrate the application of Equation 1 in evaluating the feasibility limits of RADEF system components. The limits in the radiological situation parameters for useful application of decontamination measures are of major interest here.

RADEF SYSTEM FEASIBILITY

Because of the time-phased nature of the RADEF system and the time-sequenced definition of D^*, the feasibility tests must be made on a time basis. The first system component for testing is thus the shelter. For an effective fallout arrival time of one hour after detonation, the shelter feasibility limit is given by

$$RN_1I_s = 63 \tag{2}$$

In other words, if the product RN_1I_s is equal to 63, the occupants will receive an ERD_{max} of 200 roentgens. And hence, from the above definition of feasibility, no decontamination operations can be conducted without exceeding D^*. Where the product RN_1I_s is less than 63, further operations may be considered.

To illustrate basic relations among RN_1, RN_3, and shelter stay time (but without considering the dose to decontamination crew personnel), RN_3 is plotted as a function of I_s for different assumed values of RN_1 in Figures 1 and 2 for shelter stay times of one day and one week, respectively.* For the shorter shelter stay-time, the curves show that system feasibility can be attained at higher I_s values if RN_3 is decreased, except for the lower RN_1 values. However, for the shelter stay time of one week, the feasibility becomes independent of RN_3 for RN_3 values below the dotted line; in this region of the figure, infeasibility is caused by inadequate shelter. The situations where decontamination can be used to upgrade the RADEF system and to make it a feasible one at higher I_s values than those at a RN_3 value of one are represented by the curved lines in the figures. The curves show, as otherwise would be expected, that decontamination operations would be needed more for shorter shelter stay times than for longer shelter stay times. Also, the requirement increases as I_s increases, provided the shelter protection in the early stages is adequate.

The form of the dependence of the minimum shelter stay-time on I_s for various assumed values of RN_3 (exposure dose to decontamination crews again not considered) for a shelter with an RN_1 value of 0.1 is shown in Figure 3. As might be expected, the curves show that if RN_3 is less than RN_1, the system feasibility favors a shorter stay time as I_s increases.

In the three-phase RADEF system where the dose to the decontamination crews is considered, the delay-time for crew exposure as required by the dose limits is such that useful application does not occur for RN_1 values less than about 0.1 ($I_s > 630$) and I_s values less than 200 to 300 r/hr at 1 hr ($RN_1 < 0.1$). On the other hand, the role of decontamination becomes important over a larger range of I_s values for shelter systems with RN_1 values of 0.01 and less. The earliest decontamination starting times are shown as a function of I_s in Figure 4 for several assumed conditions for the decontamination operation and its effectiveness for an RN_1 value of 0.01. The higher values of I_s at which the curves are terminated are those for which three-phase system becomes infeasible.

* A fallout arrival time of one hour after detonation applies to all the calculations summarized here.

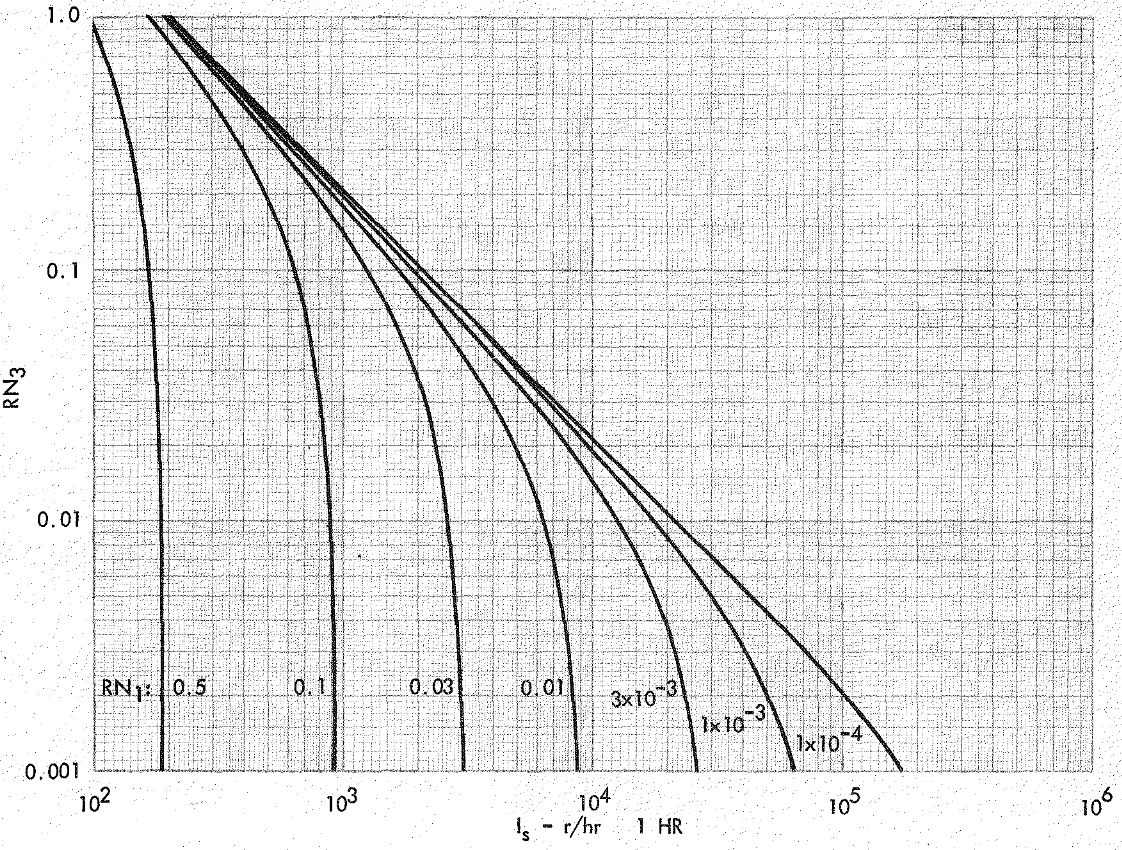

Figure 1. Maximum Values of RN_3 for Various Values of RN_1 and I_s With a Shelter-Stay Time of One Day.

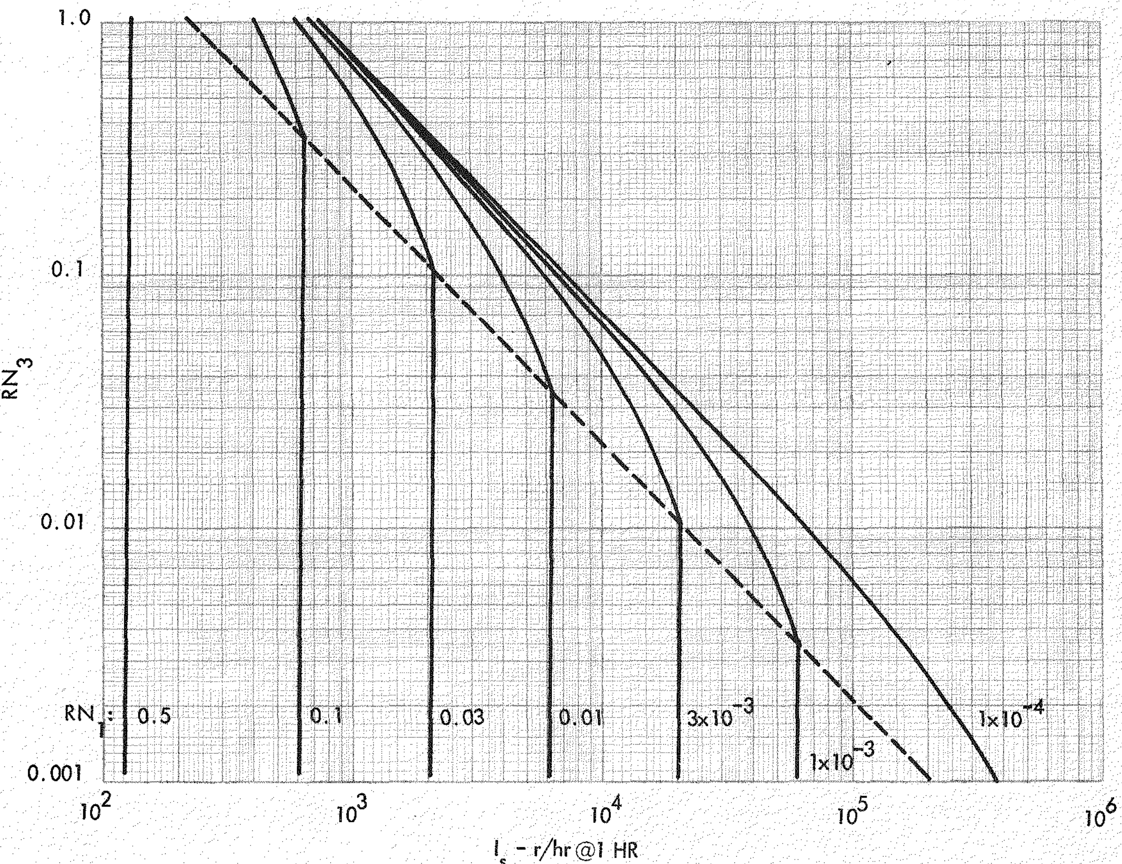

Figure 2. Maximum Values of RN_3 for Various Values of RN_1 and I_s With a Shelter-Stay Time of One Week.

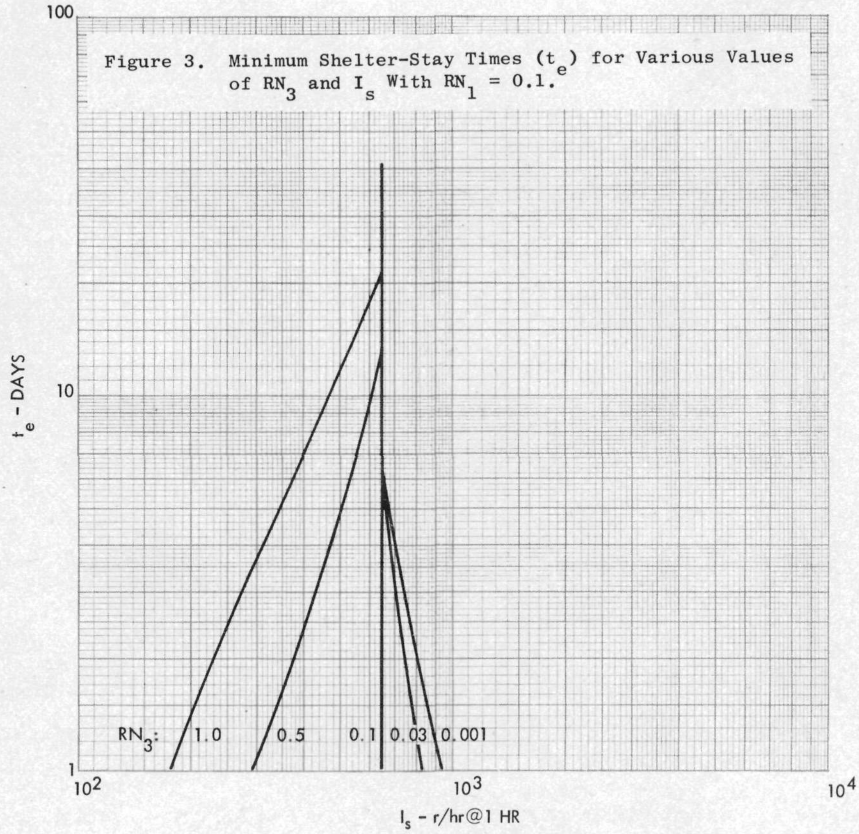

Figure 3. Minimum Shelter-Stay Times (t_e) for Various Values of RN_3 and I_s With RN_1 = 0.1.

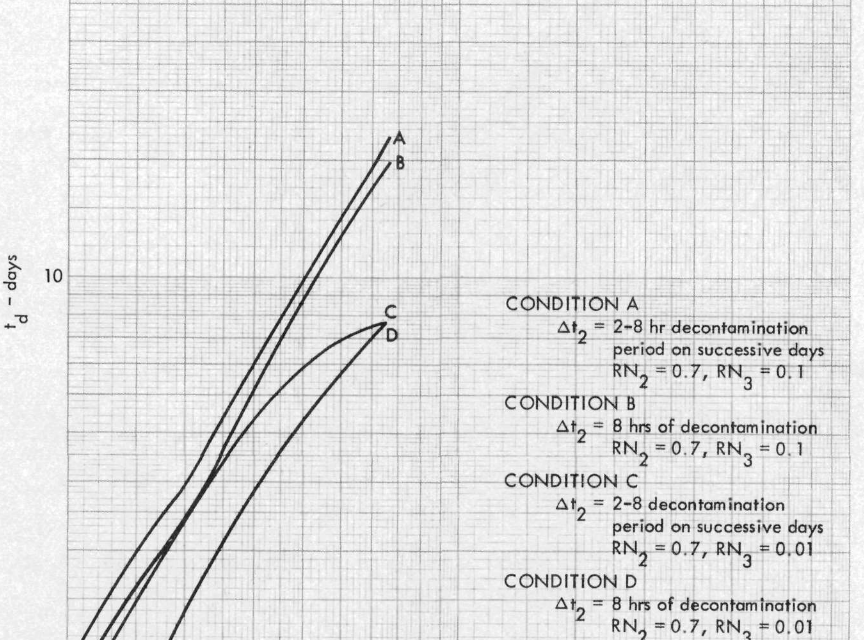

Figure 4. Minimum Decontamination Start Time for a Three-Phase RADEF System With RN_1 = 0.01.

DECONTAMINATION METHODS AND OPERATIONAL EFFICIENCIES

The variation of the effectiveness of most known decontamination methods with applied effort follows the law of diminishing returns. Further, no known method is capable of removing 100 percent of the fallout particles and radioactivity from any real surface without destroying the surface.[5] Thus, a lower limit of residual activity will remain on surfaces even after a great deal of time is spent on cleaning contaminated surfaces.

Decontamination methods for the removal of fallout from land surface detonations from surfaces such as building roofs and paved areas consist of dry methods (e.g., mechanical or manual sweeping), and wet methods (e.g., firehosing or motorized flushing). For land areas, surface removal methods (e.g., bulldozing, scraping, grading and scraping, and manual shoveling) are applicable.

The data on efficiency, or variation of decontamination effectiveness with applied effort, for dry methods may be approximately represented by

$$m = m_o^* + (m_o - m_o^*)e^{-KE} \tag{3}$$

where m_o is the weight of the deposited fallout particles per unit area of surface, E is the applied effort in equipment- or man-hours per unit area, m is the average weight of fallout particles remaining per unit area after application of the effort E, K is a constant whose value depends on the surface and method, and m_o^* is the weight per unit area of nonremovable particles. The value of m_o^* is estimated from

$$m_o^* = R(1 - e^{-km_o}) \tag{4}$$

in which R and k are constants. Derived values of K, R, and k for motorized sweeping are summarized in Table 1.

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5. Miller, C. F., Fallout and Radiological Countermeasures, Vol. II, SRI Project No. MU-4021, January 1963

The decontamination data on wet methods can be approximately represented by

$$m = m_o^* + (m_o - m_o^*)e^{-3K_o E^{1/3}} \tag{5}$$

in which

$$m_o^* = R_o m_o^n, \quad m_o \le m_s \tag{6}$$

or

$$m_o^* = R_m, \quad m_o > m_s \tag{7}$$

where R_o and n are constants and m_s is a surface saturation level above which m_o^* is constant. In Equation 5, the cube root power of E represents a degradation of efficiency for the wet methods over that for the dry methods as given by Equation 3 mainly because the wet methods pile up the particles as the method progresses along the surface whereas the sweepers pick up the particles as they move forward. Derived values of $3K_o$, R_m, R_o, and n for firehosing and motorized flushing are summarized in Table 2.

The data for land decontamination surface removal methods can be approximately represented by

$$m = m_o e^{-KE} \tag{8}$$

and the derived values of K for several of these methods when used on a clay-type soil with different surface conditions are given in Table 3. Views showing several of the methods are given in Figures 5 through 8.

In cases where the ratio m/m_o from Equations 3, 5, and 8 are approximately equal to RN_3, the required decontamination effort can be estimated. For application to a given value of I_s, information on the ratio of m_o to I_s is needed for the fallout. And, if the areas to be contaminated are specified, the time of decontamination, manpower, equipment, and supplies required can be estimated. Planning techniques for making these estimates have been developed through research sponsored by the U.S. Office of Civil Defense.[2,3]

Table 1

DERIVED VALUES OF K, R, AND k FOR MOTORIZED SWEEPING OF PARTICLES FROM PAVED SURFACES

Sweeper Type and Model	Surface	K (10^4 sq ft/equip-hr)	R (gm/sq ft)	k (sq ft/gm)
Wayne 450	Asphalt Pavement	19.8	1.95	0.025
Wayne 450	Concrete Pavement	19.8	2.10	0.036
Tennant 80	Asphalt Pavement	7.2	5.32	0.021
Tennant 100	Asphalt Pavement	12.6	1.14	0.021

Table 2

DERIVED VALUES OF $3K_o$, R_m, R_o AND n FOR FIREHOSING AND MOTORIZED FLUSHING OF PARTICLES FROM PAVED AND BUILDING SURFACES

Method	Surface	$3K_o$[a] (sq ft/equip-hr)$^{1/3}$	R_m (gm/sq ft)	R_o (gm/sq ft)	n
Firehosing	Asphalt Pavement	144	2.0	0.070	0.63
Firehosing	Concrete Pavement	144	1.0	0.038	0.53
Firehosing	Tar and Gravel Roof[b]	93.2	0.80	0.0038	0.74
Firehosing	Tar and Gravel Roof[c]	43.5	0.80	0.0038	0.74
Firehosing	Composition Shingle Roof	85.3	4.0	0.42	0.38
Firehosing	Smooth Painted Surfaces	150	0.10	0.013	0.50
Lobbing[d]	Composition Shingle Roof	80.0	4.0	0.42	0.38
CMF[e]	Asphalt Pavement	335	2.0	0.024	0.77
CMF	Concrete Pavement	335	1.0	0.027	0.63
IMF[f]	Asphalt Pavement	335	2.0	0.024	0.77
IMF	Concrete Pavement	335	1.0	0.027	0.63

a equipment = nozzle for firehosing

b fan nozzle, coefficient values based on m_o = 450 gm/sq ft of gravel plus fallout

c standard (suicide) firehose nozzle, coefficient values based on m_o = 450 gm/sq ft of gravel plus fallout

d using firehose from ground level on one- or two-story houses

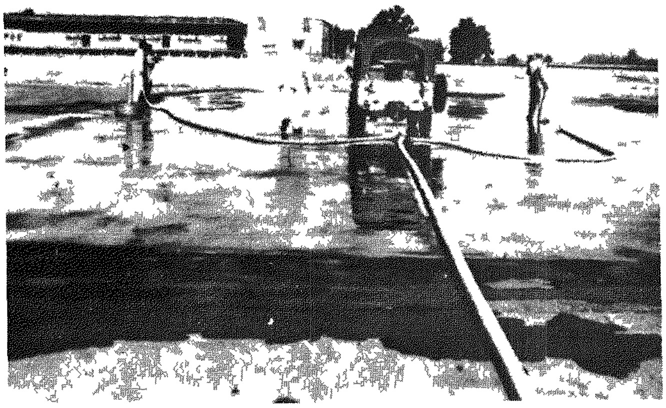
e conventional motorized flusher

f improvized motorized flusher

Table 3

DERIVED VALUE OF K FOR LAND AREA DECONTAMINATION OF A CLAY-TYPE SOIL

	K (10^4 sq ft/equip-hr)			
Method	Moist Soil Grass Cover	Moist Soil Tilled	Dry Soil Tilled	Dry Soil Untilled
Motorized Scraping	7.2	5.3	4.9	2.5
Motorized Grading and Scraping	1.5	1.8	1.6	1.8
Bulldozing	-	-	-	2.4



Two-Nozzle Team Set-Up

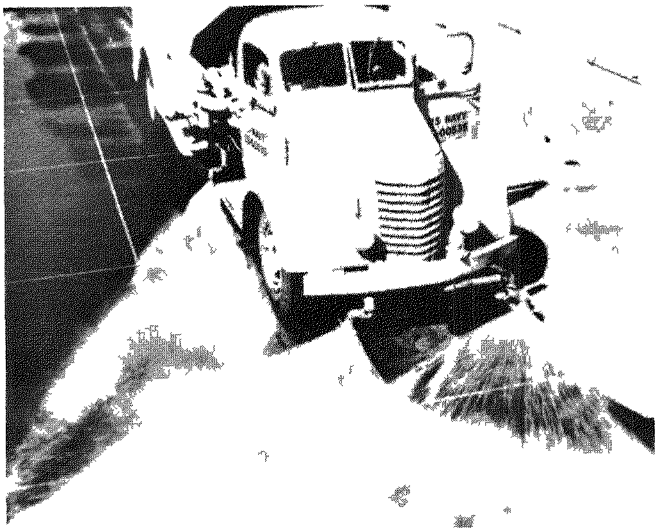
Best Water Stream Impingement Angle

Figure 5. Decontamination of Paved Areas by Firehosing

Tar and Gravel Roof Team Set-Up

Lobbing on a Sloped Roof

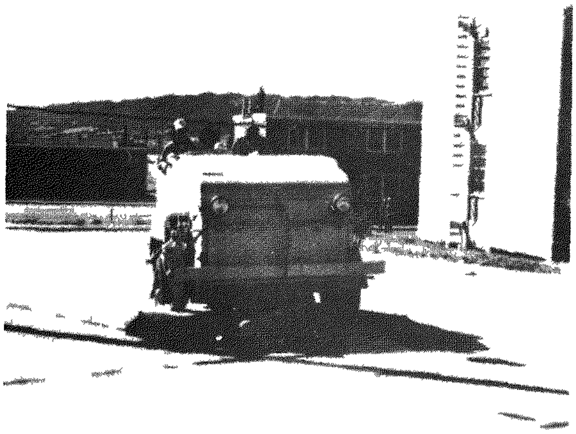
Figure 6. Decontamination of Roof by Firehosing.



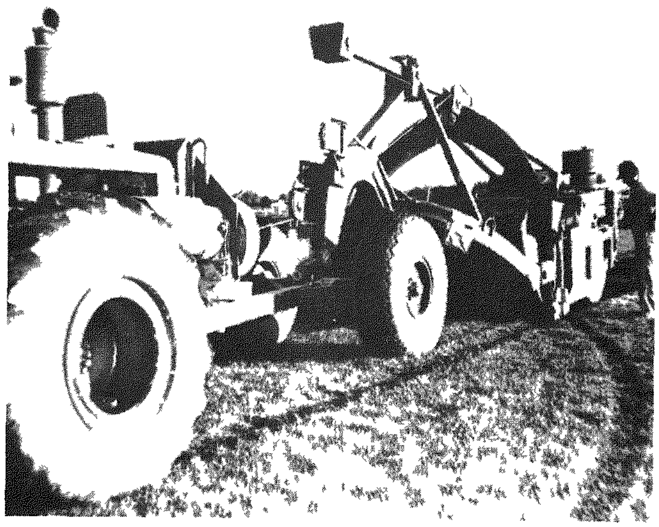
Standard Motorized Flusher

Improvised Motorized Flusher

Figure 7. Decontamination of Paved Areas by Motorized Flushing.



Motorized Sweeper



Motorized Scraper

Figure 8. Decontamination of Paved Areas by Motorized Sweeper and of Land Areas by Motorized Scraper.

FIRST RESULTS FROM THE PROGRAMME OF ACTION FOLLOWING THE PALOMARES ACCIDENT

Dr. Emilio Iranzo
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5.7

INTRODUCTION

In reply to the kind invitation of the Fachverband für Strahlenschutz, we would like to give an idea of the work which is being carried out in connection with the wellknown Palomares accident, and give indications of some of the general results obtained, with the idea that in the Symposium on Agricultural and Health Aspects of Radioactive Contamination in Normal and Emergency Conditions which is going to be held in Cordoba (Spain), organized jointly by the I.A.E.A., F.A.O., and W.H.O., we shall present more detailed studies on each of the sections we shall briefly refer to here.

As a consequence of the air crash which caused, on the 17th January 1966, the explosion of part of the conventional explosive, which was a constituent, of two thermonuclear bombs, an aerosol of plutonium and uranium was created which caused the contamination of a total area of approximately 226 hectares, of which 2.2 hectares had an alfa contamination of more than 700,000 d.p.m/ 100 cm^2, being the areas closest to the points of impact of the two bombs, which were 2,600 m. apart in a line drawn through the air.

An area of approximately 17 hectares showed contamination between 700,000 and 70,000 d.p.m/100 cm^2, and the rest, some 207 hectares, showed contaminations of less than 70,000 d.p.m/100 cm^2, rather more than half of these being less than 7,000 d.p.m/100 cm^2.

A great proportion of the houses of the town were either well out of the contaminated area, or in the parts where contamination levels were lowest. The number of persons who were in the town at the time of the accident was approximately 1,000 - 1,200.

In another communication presented to this Symposium, it has been explained how the limits of the said zones were fixed, the decontamination operations carried out, and steps taken with people and vegetation at a time soon after the accident. Here we are going to deal with, although in a somewhat summarised form, the work plan devised for the vigilance of the people and the area, and the deduction of the consequences which might, in the future, result from such an accident and the measures which were taken.

Our greatest worry, as is logical, was to determine whether or not there was internal contamination by plutonium-239 of the persons present in the area during the moments following the accident, what possibilities there were of contamination during the period of time when the operations of limit-fixing and decontamination were being carried out, and whether there was any risk from the measures which it had been decided would be taken in the areas where contamination levels were lower than 700,000 d.p.m./100 cm^2.

This risk might be derived from:

a) inhalation of plutonium if, as a consequence of the tilling of the land, and the winds which are present, an aerosol, contaminated with the said element, is created, which reach a definite diffusion.

b) contamination as a consequence of tilling operations on ground where a certain quantity of plutonium-239 was left.

c) contamination by contact with or ingestion of vegetable products which are cultivated in the area, in the case of these showing external contamination.

d) contamination of vegetable products used as foodstuffs in the case of their producing, during their growth, an absorption of plutonium-239 or uranium-235.

We make the reservation that there is no risk of contamination through drinking water, since the water existing in the said area has such a high concentration of salts that it is completely undrinkable, and the drinking water which the public consumes is brought from a distance of 50 kilometres.

As a consequence of these considerations, we summarise below the deductions obtained during the first year of work in connection with the contamination of persons, ground, air and vegetation.

CONTAMINATION IN PERSONS

The study of the determination of possible internal contamination of the people of Palomares, both in the case of those who went there afterwards, and especially those who walked through contaminated areas during the first moments, was planned under the following two aspects:

1) Determination of the Plutonium-239 excreted in urine, in order to determine the fraction which could have passed the pulmonary and lymphatic limit.

2) Determination of the quantity of plutonium-239 present in the lungs.

To obtain this information, after the analysis of plutonium-239 and total alfa activity in urine had been carried out soon after the accident, on the persons who at that time were considered those most likely to have been internally contaminated, a selection was made from the people of Palomares, with respect to the following considerations:

1) Situation nearest to the points of impact of the fractional bombs, and the areas of greatest contamination at the moment when the accident occurred, therefore with the greatest possibilities of inhaling the aerosol created in the conventional explosions.

2) Stay in zones of highest contamination during the day of the accident and the following day.

3) Residence, at the time of the accident and the days following it, in houses and areas of the town where a higher contamination had been found, within the lower limits where contamination was produced in the town, as may be seen from the plan of the contaminated area.

4) Situation during the accident and following it, in houses and areas of the town where contamination was nil, so that they could serve as controls, and at the same time we could find out with certainty whether a mistake had been made in not considering evacuation of the people of that area as necessary in the operations of contamination limit fixing and decontamination.

Taking the above factors into account, a total number of 100 persons were selected, of which 49 were males over 14 years of age, 32 were females over 14 years of age, 10 were males under 14 years, and 9 were females under 14 years.

They were taken to Madrid for the said tests to be carried out in the laboratories of the Division de Medicina y Proteccion de la Junta de Energia Nuclear. They first underwent a complete medical examination, in order to find out their state of health and take it into account in the study and subsequent epidemiological control.

In order to determine the concentration of plutonium-239 excreted in urine, three complete 24-hour samples of urine were taken from each one of the said persons, on three consecutive days. These samples were submitted to a chemical treatment in order to determine the content of the said element, by alfa spectrometry, on the final electrodeposit following a separation by ion exchange resins.

The result of this analysis showed that in 71 per cent of cases there was no indication of the existence of plutonium-239, 18 per cent showed, in some analyses, contents of less than 0.1 disintegrations per minute in the urine of 24 hours, 9 per cent showed contents of between 0.2 and 0.1 disintegrations per minute over 24 hours, and finally, 2 per cent showed a content of between 0.2 and 1 d.p.m. in the urine of 24 hours.

Bearing in mind what these values represent on the alfa spectrum corresponding to the 1000-minute measurements taken, we have taken a deliberately pessimistic view, although in almost all cases they could be considered negative.

In order to determine the pulmonary content of plutonium-239, measurements were taken on all the previously-mentioned persons, with proportional pulmonary counters, considering the region between 10 KeV-28 KeV, where the XL rays of uranium are found of 13.6, 17.4 and 20.2 KeV in an abundance of 4% per disintegration. These counters consist of two gas flow proportional chambers, with a capacity of 14 litres and a sensitive detection surface of 17.4 x 30.1 cm each, which work with a mixture of argon (90%) and methane (10%) and which have been designed in the "Los Alamos National Laboratory" by Mr. P. Dean. The calibration of the said chambers was effected with a point source of plutonium-239, and two sheets of metyl metacrylate 2.54 cm thick to simulate the tissues of the thorax.

Taking into account the background of the chambers, the counting time and their efficiency, it was found that the minimum detectable value of plutonium-239 was 40×10^{-9} Ci. In the test made under these conditions, all the values obtained were on the order of background, which indicates that the amount of plutonium-239 which might be found in the lungs, if any, would be less than 40 nanocuries, a value which is quite encouraging, as the maximum permissible pulmonary burden is 16 nanocuries.

A certain modification was made in the chambers which permitted the lowest value detectable to be reduced to 16×10^{-9} Ci. The measurements taken under these conditions with some of that people showed that in no case did the values obtained exceed this figure.

CONTAMINATION OF THE GROUND

As has already been mentioned, the contamination of the ground surface was not homogeneous. In order to determine the degree of distribution, and what this distribution was on the surface, as well as its depth, after the operations of decontamination, and those planned to eliminate surface contamination in areas required, a study has been planned in order to find out which these are. We hope that it will permit us, as years go by, to discover the dynamics of plutonium-239 in cultivated land, both as regards its dynamics parameters,

and those introduced by tilling and cultivation methods.

For this purpose, six areas have been chosen of 50 m^2 each, two from each of the 3 zones into which the total contaminated area was divided, corresponding to the two areas where the bombs fell and broke into fragments, and the intermediate zone where the town is situated. These areas were chosen in places which had remained most contaminated after the removal of a layer of earth on the areas which had contaminations higher than 700,000 d.p.m./100 cm^2. Those in zones 2 and 3 comprise areas where total alfa contaminations were found to be between 700,000 d.p.m./100 cm^2; area 2-1 belongs to a part where the upper layer of earth was also removed during decontamination operations. The areas in zone 5 showed contaminations of the order of 70,000 - 7,000 d.p.m./100 cm^2.

In order to find the average background of total alfa activity on the ground of the zone, two similar areas have been chosen, with similar geological characteristics and situated at 1,000 m. and 7,000 respectively from the zero line of the contaminated zone.

In each of the areas, and in accordance with its diagonals, during the first year, 1966, nine samples were taken which were divided into fragments, corresponding to depths of 0-5, 5-15, 15-25, 25-35 and 35-45 cm. Of the homogenised samples corresponding to each fragment, two fractions of 0.50 gm. were taken, which were submitted to chemical treatment and alfa counting, in order to determine the total alfa activity.

At present we are continuing to do this, and in successive years samples will continue to be taken at points in the same areas and following a preplanned distribution order in order to obtain complete knowledge of the dynamics of the contamination, as well as to deduce the contamination factors of the vegetable products which are cultivated in them. In 1967 the number of samples taken was higher, with a factor of two, than that of the previous year.

With these last samples, the tests have been not only to measure the total alfa activity, and consecuently, through its relationship with the values obtained in the background sampling places, and the high specific activity of plutonium-239, deduce what amount is due to the said plutonium-239. Besides radiochemical separations are being carried out for each of the contaminating radionuclids.

The alfa activity of the soil in the region of Palomares (Almeria) is one of the highest in Spain, as has been shown in the comparison of results obtained from the background areas, situated far enough away to be certain that they were not contaminated, and those from other provinces and types of soil, as may be seen from Table I.

In order to give you an idea of the results we are obtaining, in Table II may be seen the average values of alfa activity from the samples taken in 1966 from each one of the zones, and in relation to depth.

From these values it may easily be deduced that:

1) In zone 2-1, where a 5 cm layer of soil was removed, the remaining contamination is nil.

2) As a result of ploughing and breaking up of the ground, a distribution of contaminating elements have been obtained to a depth of 30 cm. Generally highest contamination levels are found in layers between 15 and 25 cm down.

3) The maximum average value of alfa activity found in the areas studied is approximately 50 times higher than the minimum value of natural alfa activity found in the background soil of the zone, which in turn is two times higher than the minimums found in the areas studied.

The unhomogeneous distribution of the contaminating particles, even after the ploughing operations carried out in order to dilute the radioactive elements, plutonium and uranium, on a layer 30-35 cm deep, is perfectly clear from the values obtained, as might logically have been expected. Even results from different samples from the same point and fragment, after the greatest homogenisation possible in the laboratory, show quite a considerable dispersion, as may be seen from Table III. On this table may be seen the values from all the analyses corresponding to each one of the fractions of ground which gave the highest alfa activity values, in area 2-2, one of those of greatest contamination.

CONTAMINATION OF THE AIR

A network of aerosoles sampling has been set up in order to discover what possibilities there might be of internal contamination of the people who live in the zone and cultivate the fields, as an isolated or related consequence of the ploughing operations on the ground and the climatological characteristics of the zone, especially those related to the low rainfall and prevailing winds.

This network consists of four sampling stations, and two for the study of the speed and direction of the winds. The samples stations are situated in the places marked on the figure S-1, S-2, P and 3-1, which respectively correspond to the zones where the two fragmented bombs fell, and one point at the urban centre of Palomares. Those for measuring the characteristics of the winds are situated at S-1 and P. In each one of these stations, at a height of 1.70 m, continuous 24-hour samples are taken, with a volume of approximately 95 m^3, every day of the year, on membrane filter paper. The samples are prepared for sending to the laboratories of the Medicine and Protection Division of JEN, where in principle, a minimum of one week after they are taken, a count is made of the total alfa activity due to radioactive elements with a long half life.

In Table IV, the average monthly values are shown for all the samples taken, during the first year of operation of the said network, at each one of the sampling stations. From the observation of the same, bearing in mind that the maximum permissible concentration in the air, for the public in general, of any mixture of alfa, beta and gamma emitting radionuclides is 4×10^{-14} microcuries/cm^3, and for plutonium-239 itself is 6×10^{-14} microcuries/cm^3, it may be deduced:

1. The average monthly values of airborne alfa activity in the area of Palomares has always been maintained below the M.P.C. Except on one occasion, in the month of August, the said average values have not exceeded one tenth of the M.P.C.
2. The maximum values of alfa activity have exceeded the M.P.C. on only seven occasions, never, however, reaching values higher than a factor of 10 over the M.P.C.
3. On the days when maximum values were found, the winds in the area had speeds of between 12 and 22 km/hr.
4. The average values of alfa activity in the district of Palomares, are comparable with those corresponding to the district of Madrid, where also,

on occasions, the maximum values found have been slightly over the M.P.C.

At present, because of the results obtained from the alfa count with the gas flow proportional counter, a radiochemical determination of plutonium in samples of air is now being carried out. For this the samples were kept, and at present are chemically treated in groups of ten days corresponding to each one of the stations. After their extraction with ion exchange resins and electro-deposition, they are measured by alfa spectrometry. In order to compare these results with those of the present background of plutonium from the contamination of the atmosphere with the said element, a sampling station was established in Madrid similar to those in Palomares.

CONTAMINATION OF THE VEGETATION

The work carried out with vegetables has tended to determine the possibilities of their external contamination, as a consequence of their cultivation in contaminated and surrounding areas, and to the study of the plants' absorption capacity, and its settling on fruits and seeds.

For the purpose, in each one of the areas previously mentioned, and in the places where the soil samples are taken, samples have been taken of the existing crops. During the first year following the accident, not all the areas were cultivated, and for this reason it was not possible to take samples from areas 2-2 and 5-1. In area 2-1, and given that it was part of an uncultivated plot, of which the upper layer of soil had been carefully removed, making sure not to destroy the existing vegetation, the tomato plant samples given in Table V in its corresponding section were taken from nearby strips of cultivated land where the upper layer of soil had not been removed.

In Table V are given, classified by areas, the average values of total alfa activity corresponding to the various vegetables collected, establishing, in some cases, a distinction between washed and unwashed vegetables, in order to be able to determine the external contamination which is easily separable from the permanent or internally absorbed contamination. From these values, the following deductions can be made:

1. Maize cultivated in a contaminated area gives a value of alfa activity superior to that which grew in the blank area, with a factor of two for the plant and three for the seed.

2. The tomato plant cultivated on contaminated soil shows a separable and fixed alfa contamination higher than that growing on blank soil. As for the tomatoes, the edible part, no difference has been found. It is logical to suppose that the findings from the plant are of an external type, and found difficult to separate by washing, due to the leafiness of the plant.

3. Both bean plants and the beans fruit show a certain amount of external contamination, proportional to the contamination of the area under cultivation. The edible part of the beans, the seeds, however, do not show the least indication of such contamination, since in the two areas their alfa activity values are less than 6 d.p.m/kg of wet weight.

4. In the only area where alfalfa is cultivated, its alfa activity was only very slightly increased.

5. The greatest degree of contamination found was in wild plants (asparagus, esparto grass and other graminaceous plants), which may possibly have existed at the moment of the accident.

TABLE I: GROSS ALPHA ACTIVITY OF SEVERAL TYPES OF SOIL IN SPAIN

PROVINCE	TYPE OF SOIL	GROSS ALPHA ACTIVITY d.p.m/g.
PALOMARES (Almeria)	2-3B GypsumBurlap	20,8 ± 1,3
	5-3B GypsumBurlap	19,6 ± 0,6
OVIEDO	Calcarenite	11,1 ± 1,7
MADRID	Akroses	12,6 ± 2,0
MURCIA	Marl	10,8 ± 2,2
BADAJOZ	Sandstones	8,6 ± 0,7
CORUNA	Granites	17,1 ± 2,2
TENERIFE	Volcanic rocks	18,5 ± 1,2

TABLE II: GROSS ALPHA ACTIVITY IN SOME AREAS OF PALOMARES

AREA	GROSS ALPHA ACTIVITY d.p.m/g.					d.p.m/g dry soil
	0-5 cm	5-15 cm	15-25 cm	25-35 cm	35-45 cm	TOTAL MEAN
2-3 B	24,5±2,8	21,6±3,2	22,3±1,8	18,7±2,8	16,9±1,3	20,8±1,3
5-3 B	20,0±1,2	19,9±1,3	20,1±1,5	20,6±1,3	17,3±1,5	19,6±0,6
2-1	11,3±2,2	9,0±1,1	10,6±1,3	11,7±1,6	9,6±1,0	10,4±0,5
2-2	472±190	376±296	851±827	10,4±1,3	9,1±0,9	344±178
5-1	48,6±35,8	28,2±16,8	90,1±72,4	12,3±1,6	11,8±1,1	38,2±14,6
5-2	13,7±4,9	12,8±1,5	11,3±1,4	16,3±6,5	13,8±2,1	13,6±0,8
3-1	24,6±2,4	30,6±6,4	13,0±1,7	14,3±3,1	11,8±1,8	18,9±3,7
3-2	215±103	182±100	1095±738	415±392	16,5±7,6	385±188

TABLE III: GROSS ALPHA ACTIVITY IN SOILS OF AREA 2-2.

AREA	PLACE	DEPTH	D.P.M./gr.						MEAN
2-2	1	0-5	681,4	34,8	150,1	8,9	77,3	6,9	159,9±106,6
"	1	5-15	11,7	94,3	7,6	7,8	14,3	6,9	23,8± 14,2
"	2	0-5	3.400,1	348,2	568,9	475,1	94,5	507,6	899,1±504,9
"	3	0-5	1.258,4	118,3	88,3	1.608,3	95,6	643,3	635,9±270,4
"	3	5-15	178,9	15,7	1.196,6	11,4	332,6	235,8	328,5±181,0
"	4	5-15	231,2	275,9	206,9	3.897,3	776,4	134,9	920,4±602,7
"	6	0-5	616,4	687,7	11,2	58,0	23,9	29,2	232,9±133,1
"	7	0-5	435,2	107,1	315,8	398,1	875,9	39,9	360,3±119,9
"	7	5-15	127,4	62,7	15,8	16,4	16,6	93,4	55,4± 19,4
"	8	5-15	23,3	20,0	5,8	23,3	21,7	35,5	18,1± 5,0
"	9	0-5	162,6	413,7	1.923,5	204,9	642,4	4.041,9	1.231,5±621,5
"	9	5-15	5.398,6	205,2	1.056,6	1.661,4	124,5	487,4	1.214,8±850,5

TABLE IV: GROSS ALPHA ACTIVITY IN AIRBORNE PARTICULATES

Mes	SAMPLING STATION. microcuries x $10^{-15}/cm^3$														
	MADRID			Station 2-1			Station 2-2			Station P (in the town)			Station 3-2		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
June	8,6	0,7	2,1	1,8	0,7	0,8	4,3	0,7	1,0	5,3	0,7	1,1	1,0	0,7	0,7
July	160	0,7	8,5	20	0,7	2,7	7,8	0,7	3,6	9,8	0,7	2,6	10,0	0,7	2,4
August	7,3	0,7	2,7	7,2	0,7	2,7	140	0,7	8,6	250	0,7	10,1	8,2	0,7	2,4
Sept.	7,6	0,7	3,8	8,9	0,7	2,9	44	0,7	3,9	9,5	0,7	2,6	43,0	0,7	4,7
October	31,0	0,7	3,5	13,0	0,7	2,5	71	0,7	4,3	5,5	0,7	2,1	3,7	0,7	1,4
November	23,0	1,0	5,2	3,9	0,7	1,5	8,8	0,7	2,2	6,1	0,7	2,1	4,9	0,7	1,4
December	9,8	0,7	4,2	9,5	0,7	2,0	14,0	0,7	2,3	4,3	0,7	1,6	9,7	0,7	2,0
January	16,5	0,7	7,7	22,0	0,7	2,3	51,5	0,7	3,4	9,8	0,7	1,5	9,2	0,7	1,7
Febr.	7,7	0,7	2,3	48,0	0,7	4,4	24,7	0,7	3,4	8,1	0,7	2,2	69,8	0,7	3,6
March	8,5	0,7	2,3	2,8	0,7	1,2	11,0	0,7	3,3	4,7	0,7	1,2	3,9	0,7	1,2
April	8,2	1,0	2,6	6,8	0,7	2,1	273	0,7	2,7	3,4	0,7	1,6	3,8	0,7	1,4
May	6,4	1,0	3,0	4,8	0,7	1,8	10,5	0,7	2,8	6,6	0,7	1,3	4,6	0,7	1,5

TABLE V: GROSS ALPHA ACTIVITY IN THE VEGETATION

VEGETATION		AREA					
		2-3 B	5-3 B	2-1	5-2	3-1	3-2
Corn (Plant) d.p.m./kg. wet	washed						
	no washed		450 ± 130			454 ± 200	933 ± 475
Corn (Seed) d.p.m./kg. dry			59			69 ± 11	185 ± 15
Tomato (Plant) d.p.m./kg. wet	washed		224 ± 75	8.472 ± 7.346	96± 30		
	no washed		407 ± 100	17.338 ± 5.817	1640±989		
Tomato (Fruit) d.p.m./kg. wet	washed		19 ± 3,4	25 ± 12	18,5±6,5		
	no washed		26 ± 6	27 ± 3,5	19,5±1,5		
Bean (Plant) d.p.m./kg. wet	washed				210± 57		659 ± 177
	no washed				177± 5		664 ± 134
Bean (Fruit) d.p.m./kg wet					11,5± 2		283 ± 158
Alfalfa (Plant) d.p.m./kg. wet	washed						
	no washed				1099±494		
Wild Plants d.p.m./kg. wet	washed	489 ± 236			363±112		
	no washed	676 ± 306		236.373±113.551			

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SOILS AND PLANTS AS INDICATORS OF THE EFFECTIVENESS OF A GROSS DECONTAMINATION PROCEDURE

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5.8

INTRODUCTION

The reports of Dr. E. Ramos and Emilio Iranzo of the Spanish J.E.N. describe the incident in which plutonium was released to the environment.

Five months after the incident, a soils-plant relationship study was initiated to obtain data relative to plutonium concentrations in the soil and the possible resulting concentrations of plutonium in the plants grown on those soils.

The soils are probably composites from several sources and vary from sand to sandy loam in texture; organic matter is generally low. Crops are grown under irrigation and with the addition of fertilizers.

Soils had been removed to various depths in some areas after the incident and replaced by soil known to be free of plutonium from the incident. All areas with the exception of 2-1 had been plowed to a depth of 45 cm. Some areas had been cultivated more than once. This treatment resulted in a complex mixing of the soil profile in the plowed layer.

METHODS

Six sites were selected within the areas known to have been exposed to plutonium; a seventh site (5-3B) about 5 kilometers to the north was selected in an area believed to be free of plutonium. In September 1966 another site (2-3B) about 15 kilometers to the north was sampled; the seventh and eighth sites served as controls. A 50 x 50 meter square served as the sampling site with 9 sampling points on the diagonals. Cores were taken in duplicate at each point at depths of 0-5, 5-15, 15-25, 25-35, and 35-45 cm for a total of 90 samples per site. Vegetation associated with each point was obtained where available.

The complete method of analysis for plutonium will be published elsewhere. In brief, it entailed digestion of an aliquot of the sample (about 50 grams for plant and 1 gram for soils), and centrifugation followed by conversion of the plutonium to the tetravalent state and sorption of the plutonium on AG 1-X2 (Dowex) ion exchange resin (0.15 to 0.30 mm in diameter). The sorbed plutonium was eluted from the column and electroplated for 5 hours. The electroplated plutonium was counted in low background alpha scintillation equipment. The average background of the counters was 0.02 d/m and average recovery from a standard plutonium solution was 75%.

RESULTS

Two observations are important.

(1) In general, the highest concentrations of plutonium were found in the 0-5 cm depth, and

(2) A wide range in plutonium concentrations was found in a single sample from which aliquots were taken.

Average results for each depth and each plot are listed in Table I.

TABLE I. PLUTONIUM CONTENT IN SOILS - AVERAGE (d/m/gram - dry)

Plot No.	Depth (cm) 0-5			5-15			15-25			25-35			35-45			Plot Average All Depths
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	
2-1	0.2	5.6	37	0.2	1.9	8	0.2	6.4	48	0.2	2.6	16	0.2	4.6	46	4.2
2-2	6	294	990	3	80	695	0.2	2.6	9	0.4	2.6	9	0.1	2.4	12	76.7
3-1	0.6	343	4680	0.6	13.8	58	2	27	209	0.4	7.2	53	0.9	18	130	81.8
3-2	1	75	556	1.2	76	268	2	27	198	0.9	2.7	6	0.3	3.3	13	37.0
5-1	0.8	3.1	10	0.7	3.5	14	0.3	3.0	13	0.1	3.3	24	0.2	3.3	11	3.2
5-2	0.1	1.9	9	0.2	1.6	8	0.2	1.2	7	0.1	2.0	11	0.1	3.5	20	2.0
Depth Average All Plots		120			29.5			11.2			3.4			5.9		34.0
Control Plots																
2-3B*	0.3	2.8	8	0.6	1.6	4	ND**	1.0	3	ND**	1.6	2	0.4	2.3	5	1.9
5-3B	0.2	2.0	4	0.1	1.8	7	0.1	7.9	11	0.1	2.8	16	0.1	1.4	5	3.2
Depth Average All Plots		2.4			1.7			4.5			2.2			1.9		2.6

*Samples taken September 1966.
**Not detected

The higher concentration at the 0-5 cm level may result from the manner in which dry, sandy soil breaks over the moldboard of the plow or may be due to later cultivation practices which returned some buried soil to the surface. A study of other methods of burial by plowing is projected.

A study has shown that the wide range in concentration is accounted for by a wide range in particle size. If one assumes a single particle of PuO_2 0.6 µm in diameter, a count of about 0.2 disintegrations per minute results; a particle 18 µm in diameter will produce about 4,680 disintegrations per minute.

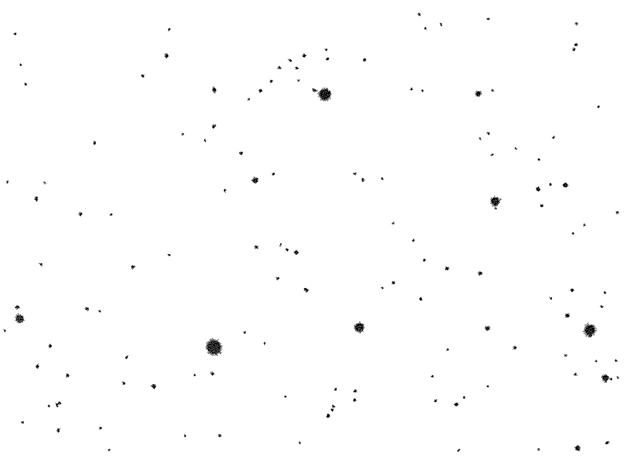

Fig. 1. Particle size range in excavated soils removed from near impact area

Soil which was removed from the site and taken to the USA for burial contained about 10^3 to 10^4 times the amount of plutonium found in the remaining area. The autoradiograph, Fig. 1, shows the observed relative particle size encountered in those soils collected from near the impact area of the device. The range of particle size is obvious and substantiates the observed range in concentrations of plutonium per aliquot of soil sample. Data relative to observed d/m/aliquot from a single sample are presented in Table II. It is believed that these numbers do represent plutonium content in the aliquots, but they also present a problem in attempting to define levels of plutonium content over large areas. A standard approach to the treatment of such data would be of value.

TABLE II. VARIATION IN OBSERVED ACTIVITY IN ALIQUOTS FROM A SINGLE SOIL SAMPLE, PLOT 2-2

Aliquot	1	2	3	4	5	6	7
d/m/gram (dry)	455	778	0	28	8	53	45
Average							195

Cultivated and wild vegetation have been obtained for four different sampling periods from June 1966 through December 1967. Results obtained from 51 samples of tomato fruit and 21 samples of tomato plant are presented in Table III. Data are reported for washed and unwashed plant and fruit obtained from Areas 2-2, 5-1, and 5-2 and from the control area 5-3B. There is some indication that washing the plant by immersion in water removes some activity; however, washing the fruit has little effect on the observed concentration of plutonium.

TABLE III. AVERAGE PLUTONIUM ACTIVITY IN TOMATOES

Treatment	d/m/gram (wet)	Soil Average d/m/gram (dry)
Plots 2-2, 5-1, 5-2		
Washed plant	5.83	27
Unwashed plant	2.82	27
Washed fruit	.0028	27
Unwashed fruit	.0027	27
Plot 5-3B (Control)		
Washed plant	.066	3.2
Unwashed plant	.109	3.2
Washed fruit	.0009	3.2
Unwashed fruit	.0003	3.2
USA Control	.0007	1.2

Factors which might contribute to the observed plant-fruit difference are:

(1) the longer time of exposure of the plant to the environment than the fruit,

(2) the smooth surface of the fruit compared to that of the plant leaf, and

(3) in the case of beans and maize, the natural protection of the bean seed by the pod and maize seed by the husk.

A consideration of the possible health hazard of the average concentration of 0.0028 d/m/gram of wet fruit in comparison to the MPC_w* for plutonium leads to the conclusion that 10^3 kg of tomatoes may be ingested per day without harm; hence a health hazard may be considered nonexistent.

TABLE IV contains data on 24 samples of washed and unwashed maize plants and 13 samples of dry maize seed. A calculation similar to the above would allow for the consumption of 28 kg of maize seed per day without harm. Again, there is no apparent health hazard.

*Maximum permissible concentration in drinking water.

TABLE IV. AVERAGE PLUTONIUM ACTIVITY IN MAIZE

Plots 3-1, 3-2, 5-2

Treatment	d/m/gram (wet)	Soil Average d/m/gram (dry)
Washed plant	.0235	40.3
Unwashed plant	.4234	40.3
Seed (dry)	.1235*	40.3

*Level in 1 sample 12 x average of other 12.

Plot 5-3B (Control)

Treatment	d/m/gram (wet)	Soil Average d/m/gram (dry)
Washed plant	.0470	3.2
Unwashed plant	.0585	3.2
Seed (dry)	.0863	3.2
USA Control	.018	1.2

Data relative to plutonium concentration in bean plants and seed are reported in Table V. Bean seeds had a higher plutonium concentration than tomatoes by a factor of about 3; however, the health hazard is again nonexistent. Washing removed some surface contamination from the plants. Five samples of seed and 10 samples of plant were analyzed.

TABLE V. AVERAGE PLUTONIUM ACTIVITY IN BEANS

Plots 3-2, 5-2

Treatment	d/m/gram (wet)	Soil Average d/m/gram (dry)
Washed plant	.024	19.5
Unwashed plant	.114	19.5
Seed (dry)	.007	19.5

Results obtained from 20 samples of alfalfa are reported in Table VI. Conclusions are similar to those reported for maize, i.e., a benefit derived from washing and the absence of a health hazard.

TABLE VI. AVERAGE PLUTONIUM ACTIVITY IN ALFALFA

Plot 5-2

Treatment	d/m/gram (wet)	Soil Average d/m/gram (dry)
Washed plant	.0439	2.0
Unwashed plant	.1576	2.0

Plutonium concentrations have been determined on 64 samples of wild plants of a variety of species. Results are presented in Table VII. Plants, such as Gramineae, which produce a seed head of many awns were highest in plutonium concentration. It is probable that the plutonium found is external, since in fruit such as that of prickly pear, the plutonium content of the peel was about 40 times that of the fruit from which the peel had been removed. Lack of rain in the area would allow the particle to remain on the awn for extended periods of time.

TABLE VII. AVERAGE PLUTONIUM ACTIVITY IN WILD PLANTS

Plots 2-2, 2-1

Treatment	d/m/gram (wet)	Soil Average d/m/gram (dry)
Washed plant	27.36	40.9
Unwashed plant	26.63	40.9
Washed fruit	.0037	40.9
Unwashed fruit	.163	40.9
Peeled fruit	.0042	40.9
Peel	.1627	40.9

Plot 2-3B (Control)

Treatment	d/m/gram (wet)	Soil Average d/m/gram (dry)
Washed plant	.136	1.9
Unwashed plant	.059	1.9

Results of radiochemical analysis for plutonium in water from one well and the associated open storage tank are presented in Table VIII. Water from the wells is used for human consumption as well as for irrigation. The aquifer varies in depth but averages about 50 meters. Plutonium was not detected in water taken directly from the well.

TABLE VIII. PLUTONIUM CONTENT-TANK AND WELL SAMPLES

Sample	Date Sampled	d/m/liter
Well #1		
Direct from Pump	December 1967	Not detected
Tank only	December 1967	Not detected

CONCLUSIONS

Data obtained from the analysis of about 1,300 samples of soil, vegetation, and water for plutonium indicate that no health hazard exists from the intake of such vegetation as tomatoes, maize, alfalfa, or beans grown on the areas where plutonium was released. The absence of a hazard may be credited to the method of decontamination, the initial low levels of plutonium, or both.

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TOWARDS INTERIM ACCEPTABLE SURFACE CONTAMINATION LEVELS FOR ENVIRONMENTAL PuO_2 *

5.9

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INTRODUCTION

Metallic ^{239}Pu is being used in increasing quantities for reactor fuels and for nuclear warheads. Although the probability is quite small, an appreciable amount of plutonium could be involved in a fire, explosion, or other incident causing contamination of the surrounding area. An incident of this type occurred near Palomares, Spain, in January 1966, when two U.S. Air Force planes collided in midair. Two plutonium-bearing weapons contaminated a significant area of the countryside, and rather extreme decontamination efforts were employed over a portion of the area.(1) The cost of this operation has been estimated at 50 million dollars, of which only about 5 million dollars was expended in recovery of the weapon lost in the sea. A second incident, quite similar to the one at Palomares, occurred early this year. At the time of this writing, specific data regarding the extent of environmental contamination are not available.

The probability of a serious accident has been computed for several modes of shipment, based on available information (U.S.A.) of accident frequency and severity.(2) For certified all-cargo commercial aircraft, this probability is 1/42,000 per 1,000 miles traveled. For other modes of commercial shipment, the probability of a serious accident per 1,000 miles is a factor of 2 to 4 less.

Evaluation of the degree of hazard resulting from such an accident is not an easy task, because few data apply directly to a specific field situation. Many factors need to be considered, and where data are lacking, reasonable yet conservative assumptions should be made.

This report will consider briefly the physical and biological factors pertinent to the establishment of acceptable surface contamination levels for environmental $^{239}PuO_2$. The practical difficulty of actual field measurement of these levels will be omitted, as will discussion of the economic, social, psychological, moral, and other intangible factors. Presented below is a brief analysis of the surface contamination hazard from a serious accident involving release of ^{239}Pu. Rather than provide a complete literature survey, an overview has been made with pertinent references cited.

CHEMICAL AND PHYSICAL FORM

For the practical purposes of hazard evaluation, plutonium metal might be considered as composed wholly of the fissile isotope 239. Although small amounts of $^{240-242}Pu$ and ^{241}Am may be present along with other radioactive impurities, these nuclides do not appreciably alter the hazards evaluation,

* This paper is based on work performed under United States Atomic Energy Commission Contract AT (45-1)-1830.

since the radiotoxicity of these nuclides is of the same order as ^{239}Pu. For some applications (e.g., neutron sources), ^{238}Pu may be the predominant isotope, but generally such applications are few, and the total quantity used is small when compared with that of ^{239}Pu. Furthermore, since the radiotoxicity of the two isotopes is similar, the discussion below generally applies to ^{238}Pu as well.

Because of the high chemical reactivity of plutonium and the probable nature of the accident (viz., giving a rise to a fire), PuO_2 is the assumed chemical form in the environment. This compound is generally considered to be insoluble, and the degree of insolubility is a function of the oxidation temperature.(3) High-fired oxide is most highly insoluble, while oxide produced by auto-oxidation at room temperatures produces the most soluble form of the oxide.

The physical form of the plutonium is assumed to be particulate, with log normal distribution and a mass median aerodynamic diameter (MMAD) of 1 to 2 μ with σ_g = 1.5 to 2.0. This implies a count mean aerodynamic diameter of 0.5 to 1.0μ. This particle size distribution, although not the "worst possible case" from an inhalation standpoint, is conservative and has been inferred from experimental studies.(4-7) Stewart,(6,7) for example, in experiments in which metallic plutonium was burned, found that the mass median diameter (MMD) of the airborne fraction of Pu ranged from 0.3 to 29 μ. Similar particle size distributions were reported by Ettinger et. al. (5) and Andersen.(4) Note that the particle size distribution of PuO_2 will vary with ignition temperature; the higher the ignition temperature, the larger the particle size.(7)

ECOLOGY AND FATE OF PLUTONIUM IN THE ENVIRONMENT

Limited data obtained from a series of experiments in Nevada indicate that once deposited, plutonium tends to remain in place on the ground surface.(8) Other data confirm this fact, and indicate that the Pu would remain within the top few inches of soil. The amount of deep leaching into the soil and into the water table would be small, and soil, in fact, acts as a good filtering medium to keep the plutonium out of the ground water. Rain and subsequent runoff, however, might concentrate the plutonium in reservoirs, ponds, lakes, and other bodies of water. If, for example, the Pu is concentrated in puddles which later evaporate, "hot spots" might be created. Data in these areas of concern are not readily available, and generally raise more questions than they answer, including such points as translocation mechanisms, effects of bacterial action, and weathering.

A certain fraction of the plutonium deposited on the ground or other flat surface can be resuspended to give significant air concentrations. A good deal of effort has been devoted to the study of resuspension factors (5-7,9-17), and reported values for plutonium and its compounds range over 11 orders of magnitude!(15) Although some correlation exists among type of surface, wind, and resuspension, the particle size (within limits) and, to a lesser extent, the contamination level seem to make little difference. The plutonium air concentration will vary according to the height above the contaminated surface. Obviously, in enclosed rooms with considerable air circulation, air concentrations will be greater than in rooms with still air or in large open areas.

The resuspension factor (RF), according to at least one study, appears to grow smaller as the material ages.(15) Thus, the air concentrations over

a contaminated surface will be reduced with time. This "air concentration half life" ranges from 30 to 60 days,(15,16) and 45 days was selected as a reasonable value. Reduction of airborne plutonium is a result of weathering, translocation, and other conditions which bind the Pu to the ground. Weathering is probably the most important single factor affecting the airborne Pu levels.

Review of the available pertinent literature would indicate that a RF of 10^{-4} M^{-1}, although conservative, is appropriate. In support of this value the data of Stewart(17) is particularly germane. For deposition from a series of weapons experiments with both plutonium and uranium, resuspension factors as great as 7×10^{-4} M^{-1} were seen. For outdoor conditions with moderate activity, Stewart proposes a value of 10^{-5} to 10^{-4} M^{-1} as a guideline. For quiescent outdoor conditions, 10^{-6} M^{-1} is suggested.

Working with PuO_2, Jones and Pond(14) found an average RF of 5×10^{-5} M^{-1} in a laboratory with a person moving across the floor at the rate of 36 steps per minute. In enclosed rooms with considerable movement, RF's of 10^{-4} to $>10^{-3}$ M^{-1} have been reported.(10,12) These latter situations are somewhat analogous to a house into which contamination has been tracked from the outside, and in which the occupants are carrying on normal living activities.

Other confirmatory data can be obtained from industrial experience with uranium.(9) However, the data are not always applicable to the widespread environmental case. Much of the available environmental data, notably the Plumbbob results,(8,11,16,17) are questionable when carefully scrutinized. The absence of adequate data strongly justifies selection of a conservative RF, and 10^{-4} M^{-1} appears satisfactory at this time.

The ecology of environmental PuO_2 is of singular importance, yet there is a paucity of pertinent data relating to plutonium in man's food chain. The few studies of plutonium uptake by plants growing in contaminated soil (16,18-20) indicate that the uptake by the leaves is quite small. Even when $Pu(NO_3)$, which is more soluble than PuO_2, was used, the concentration in plant leaves was only about 0.01% that of the concentration in the soil. The concentration in the roots were much greater. Data are available for barley, beans, and peas;(18-20) however, no data are given for root crops (e.g., carrots) or perennials.

Concentration of Pu in the tissues of animals used for food is not to be expected. Gastro-intestinal absorption of Pu is small(21-22), and in the event of uptake, most of the plutonium would deposit in inedible portions of the animal, such as the bone, or in the liver. When these factors are combined with the small amount of plutonium expected in plant foods eaten by the animals, this potential source or reservoir of plutonium is negligible, at least when considering the hazard to man.

THE NATURE OF THE HAZARD

Contamination of the environment by PuO_2 would primarily present an internal radiation hazard to the populace. Of the three basic routes of entry, the percutaneous would seem to be the least hazardous unless a fairly large amount of contaminant were introduced through the broken skin.(24) Percutaneous absorption through the unbroken skin and skin exposure are negligible, although a few particles of PuO_2 in a wound might cause problems. This latter case would be exceptional however. Entry by the ingestion route

is far less likely to create a hazard(24,26) because the fractional uptake from the human gut is only 0.003%(21) for ingested Pu. Hence, even if the Pu were concentrated in foodstuffs, the uptake from ingestion would be small. And, only with millicurie/day intakes would the dose to the G.I. tract be sufficiently great to cause concern.

The inhalation hazard of PuO_2 greatly exceeds the ingestion or percutaneous hazard and is the limiting factor. This is partly attributable to the small mass of the pulmonary lymph nodes, 20 gm,(27,28) and the fraction of inhaled dust retained in them.(29-34) This fraction is about 2% for PuO_2 particles of the type specified earlier.(29) (Certain questions, of course, remain unanswered: e.g., How much Pu crosses the placenta and is incorporated into the fetus? Questions of this nature, however, refer to rather specific cases and can only be resolved by further experimental work beyond the scope of this evaluation). Using the International Committee on Radiological Protection task group model for lung clearance,(29) the lymph nodes will be the critical organ, primarily because of their small mass and the essentially infinite (from a biological point of view) effective half-life of the PuO_2 particles deposited in them.

It is difficult to assess, or even to compute, a permissible level of exposure. Biological parameters are defined by Standard Man data, and the 1965 ICRP Recommendations(29) also provide an indication of acceptable risk. The ICRP promulgates a Dose Limit of 1.5 rem/yr to the lungs of a population group exposed to controllable sources. For disaster type situations or emergencies, the only guideline given is essentially "judicious decision making." In general, the Committee, as well as this inquiry, advocates an actual dose as near zero as possible. However, for a population group in a plutonium contaminated environment, a limiting lung dose of 1.5 rem/yr may well be acceptable. Although desirable, it may not be practicable to reduce area contamination levels to zero following a release; therefore, acceptable levels for environmental PuO_2 have been calculated, based on the following premises:

1) Decontamination efforts to reduce surface contamination below these levels are not feasible.
2) PuO_2 or other insoluble α emitters of similar hazard are the primary source of contamination.
3) An acceptable risk is 1.5 rem/yr to the adult pulmonary lymph nodes.(29)
4) Technical data:

Particle Size: 2 μ MMD
$\sigma_g \sim 1.5$

20% deposition in pulmonary compartment, with 15% of this quantity transferred to the pulmonary lymph nodes.(29)

Mass of pulmonary lymph nodes = 20 g.(27,28)

T_{EFF} in pulmonary lymph nodes = ∞ for 90% particles; and 360 days for remainder.(29)

Ground to air resuspension factor: $\sim 10^{-4}$ M^{-1}.

Air concentration half life = $\sim$ 45 days.(11)

Pulmonary compartment to lymph node transfer half life = 360 days.(29)

Thus, approximately 3.2×10^{-5} μCi in the adult pulmonary lymph will produce a dose of 1.5 rem/yr, as indicated by the calculation below:

The quantity, q, of ^{239}Pu (in μCi) in the pulmonary lymph nodes that will provide a dose rate, $\frac{d\ rem}{dt}$, of 1.7×10^{-4} rem/hr (= 1.5 rem/yr) can be computed by

$$\frac{d\ rem}{dt} = \frac{k_1\ k_2\ q\ \ \Sigma EF(RBE)n}{k_3 m}$$

in which k_1 is a constant equal to 1.33×10^8 dis/hr/ μCi,
k_2 is a constant equal to 1.6×10^{-6} ergs/MeV,
k_3 is a constant equal to 100 erg/g/rad,
Σ EF(RBE)n is the effective absorbed energy in MeV-rem/dis-rad,
and m is the mass of the pulmonary lymph nodes, in grams.

Putting in the values for the constants, and solving for q,

$$q = \frac{100 \times 20 \times 1.7 \times 10^{-4}}{1.33 \times 10^8 \times 1.6 \times 10^{-6} \times 53} = 3.2 \times 10^{-5}\ \mu Ci.$$

This quantity can be related to an initial ground contamination level, C_o, by the equation

$$\begin{aligned} q &= \int_0^t C_o\ (RF)\ e^{-\lambda_c t}\ J\ f_p\ f_x\ (1 - e^{-\lambda_x t}) \\ &\quad - f_L\ (\text{previous term})\ e^{-\lambda_L t}\ dt \\ &= \int_0^t C_o\ (RF)\ e^{-\lambda_c t}\ J\ f_p\ f_x\ (1 - e^{-\lambda_x t})(1 - f_L e^{-\lambda_L t})\ dt. \end{aligned}$$

In this equation, the terms are defined as shown:

C_o is the initial ground concentration, in $\mu Ci/m^2$.

RF is the resuspension factor.

λ_c is the air concentration reduction factor, in days^{-1}, which is equal to $\frac{0.693}{45} = 0.014$. The 45-day quantity refers to the air concentration half-life; see supra.

J is the breathing rate, taken as 20 m^3/day.

f_x is the fraction transferred from the pulmonary compartment to the pulmonary lymph nodes.

f_p is the fraction of inhaled particles deposited in the pulmonary compartment.

λ_x is the clearance constant for f_x.

f_L is the fraction cleared from the pulmonary lymph nodes, and

λ_L is the clearance constant for f_L.

For any given particle distribution, the constants f_p, f_x, λx, f_L, and λ_L can be obtained from the ICRP Task Group data.(29) For PuO_2 with the particle distribution assumed above, the appropiate values are:

$$f_p = 0.25$$

$$f_x = 0.15$$

$$\lambda_x = \frac{0.693}{360} = 2 \times 10^{-3}/\text{day}$$

$$f_L = 0.1$$

$$\lambda_L = \frac{0.693}{360} = 2 \times 10^{-3}/\text{day}$$

If t, the time in the contaminated area, is taken as 50 years, and the integral solved for C_o, the following values are obtained:

$$C_o \approx 0.04\ \mu\text{Ci/m}^2$$
$$\approx 0.7\ \mu\text{g/m}^2$$
$$\approx 10^3\ \text{dis/min per 100 cm}^2$$

The value chosen for the superior limit of the integral is not critical because almost the entire lung burden will be accumulated within the first six months. The levels cited above would apply to an urban area fairly uniformly contaminated with plutonium. Other factors will affect the permissible levels of plutonium contamination, including the land area involved, the land use, and the population density. Lower levels are indicated within a densely populated urban area as opposed to open rangeland or desert, since more people will be exposed, thereby increasing the number of persons who may be adversely affected. The population characteristics are also important, for infants and children or other classes of people might be more susceptible to adverse effects. However, data are lacking in this area of interest, and so only the general case was considered.

Land use considerations were made subjectively, and the following interim maximum permissible surface contamination levels were derived for four land use categories.

The levels cited in Table I are based primarily on inhalation hazard, not ingestion. In the case of farming operations, possible concentration by edible root crops (e.g., carrots, turnips) or by food animals and in milk was considered. However, the need for further study of the ecology of environmental plutonium cannot be too strongly emphasized. Note that the levels cited appear satisfactory for children also, partly because the long equilibration time and smaller breathing volume offset the reduced mass of the pulmonary lung nodes and the possible increase in radiosensitivity.

<u>TABLE I.</u> Interim Maximum Permissible Surface Contamination Levels for Environmental PuO_2

Urban, suburban, and recreation areas	<u>Average</u>: 10^3 dis/min per 100 cm^2 (0.04 $\mu Ci/m^2$) <u>Maximum</u>: 10^4 dis/min per 100 cm^2 (0.7 $\mu Ci/m^2$), spread over $\leq$10% of the total area included
Rural: truck farming, annual food crops, grazing land, milkshed, etc.	<u>Average</u>: 10^4 dis/min per 100 cm^2 (0.4 $\mu Ci/m^2$)
Rural: deep root perennials (e.g., nuts, certain fruits)	<u>Average</u>: 10^5 dis/min per 100 cm^2 (4 $\mu Ci/m^2$)

Remote or Controlled: desert, forest, fenced or limited access areas.	Average: 10^6 dis/min per 100 cm^2 (4 $\mu Ci/m^2$)

COMPARISON WITH OTHER STANDARDS

The literature abounds with suggested maximum surface contamination levels, some of which have been written into law and are tabulated in Table II. With the exception of the U.S.S.R., which is far more restrictive, all are within reasonable agreement with the most restrictive level cited in Table I. However, these levels refer to the industrial or work situation, and hence, are not strictly comparable with environmental levels. Dunster, (38-41) who has extensively studied contamination hazards, advocates 10^{-5} $\mu Ci/cm^2$ (2200 dis/min per 100 cm^2) for widespread areas contaminated with plutonium, and his work essentially stands alone.

TABLE II. Summary of International Permissible Alpha Contamination Levels Written into Law.

Country	Maximum Permissible Alpha Contamination ($\mu Ci/m^2$)	Application	Reference
Czechoslavakia	0.11	Workplaces, after decontamination	35
France	0.01	Skin	36
	0.1	Equipment and workplaces in "inactive" areas	
	1.0	Equipment and workplaces in "active" areas	
Poland	0.1	Laboratories restricted to 100 μCi	35, 36
	1.0	Laboratories in which 100 μCi permitted	
South Africa	0.1	Body, personal clothing, inactive areas, etc.	35
	1.0	Equipment and workplaces inside controlled areas	

TABLE II. (contd)

Country	Maximum Permissible Alpha Contamination ($\mu Ci/m^2$)	Application	Reference
United States	0.02	Interstate Commerce Commission (Department of Transportation), pertains to interior of vehicles previously used for transportation of radioactive materials	37
U.S.S.R.	0.015	Work Clothing and surfaces before cleaning	35
	0.002	Hands and work underclothing, before cleaning	
	0.006	Work surfaces, after cleaning	
	Background	Hands and work underclothing, after cleaning	
United Kingdom	0.1	"Inactive" areas	36
	1.0	"Active" areas	

Generally, suggested or required maximum permissible surface contamination levels for both work and non-work environments agree with those cited in Table II or by Dunster. However, there is one notable exception: the U.S. Department of Defense. The level of 62 $\mu Ci/m^2$ (1.34×10^6 dis/min per 100 cm^2) has been promulgated by the U.S. Air Force.(48) This level is two to three orders of magnitude greater than contemporary health physics practice,(43-46) and about 4 orders of magnitude higher than those suggested by Dunster.(38-41) The Navy publication PORRAC, without regulatory status, indicates a final clearance level acceptable for unrestricted release as about 0.04 $\mu Ci/m^2$ (800 dis/min per 100 cm^2).(47) However, another Navy publication has suggested an alpha contamination level of 0.62 $\mu Ci/m^2$ (1.34×10^4 dis/min per 100 cm^2) has been suggested for shipboard occupancy on a continuous basis.(48-49)

Although such a discussion could be carried on at considerable length (perhaps _ad infinitum!_), the point has been made: considerable confusion exists with respect to alpha contamination limits in the environment. Existing standards are based upon woefully inadaquate data; often a conservative approach is not utilized. More information is needed, especially regarding the fate of plutonium (and other alpha emitters) in the environment. Until such information becomes available, the interim standards of Table I are put forth as consistent with good health physics practice.

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As an alternative to either of the foregoing schemes one could adopt an arbitrary schedule of allowable exposure in the various circumstances anticipated in war or civil defense. The difficulty in reaching agreement on any arbitrary schedule was, of course, one of the principal reasons for suggesting the ERD scheme. Thus, it appears that we may be back where we started from.

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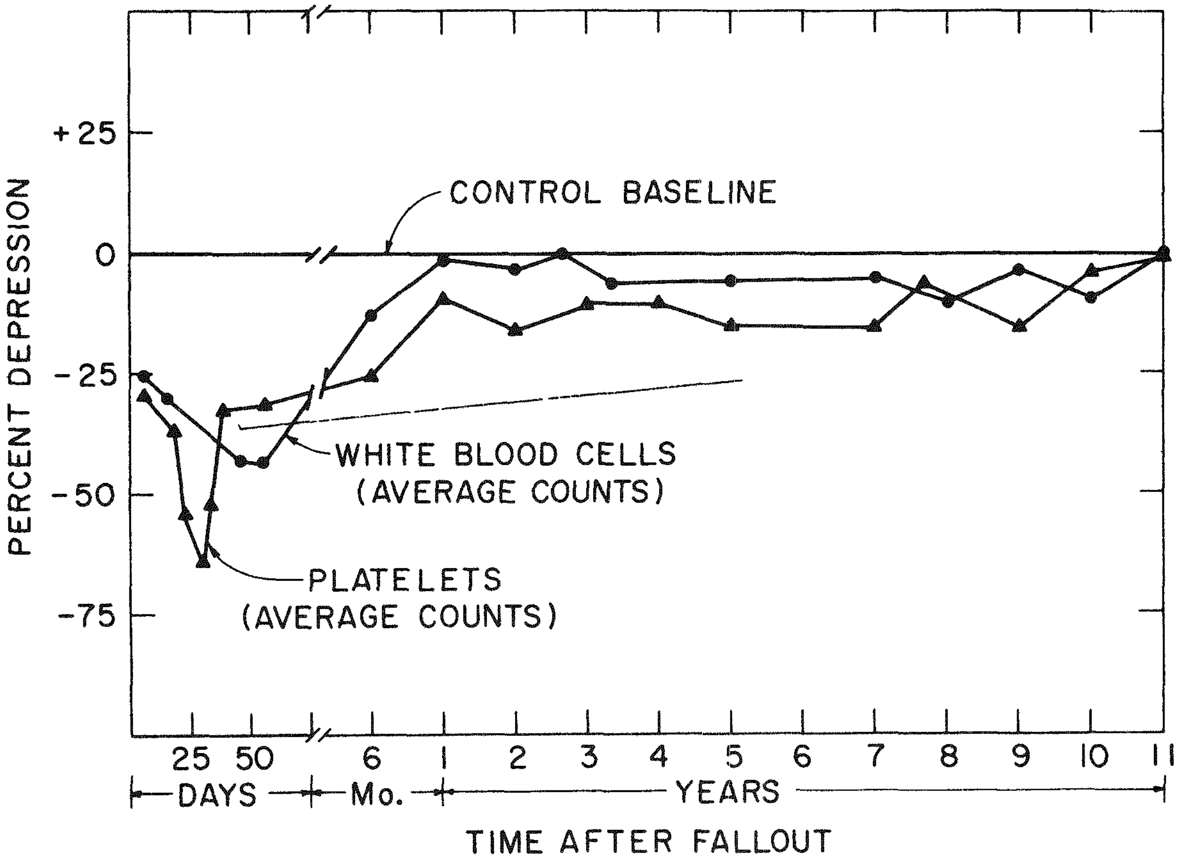

Figure 1

<u>Blood Counts and ERD</u>

Duration of exposure, days	Dose-rate R/day	Lowest value after termination of exposure, as percent of normal			
		WBC	Lymphocytes	Platelets	Reticulocytes
Single-shot, 1-2	200	70	60	35	50
10	40				
30	12				
90	6				
365	3				

Figure 2

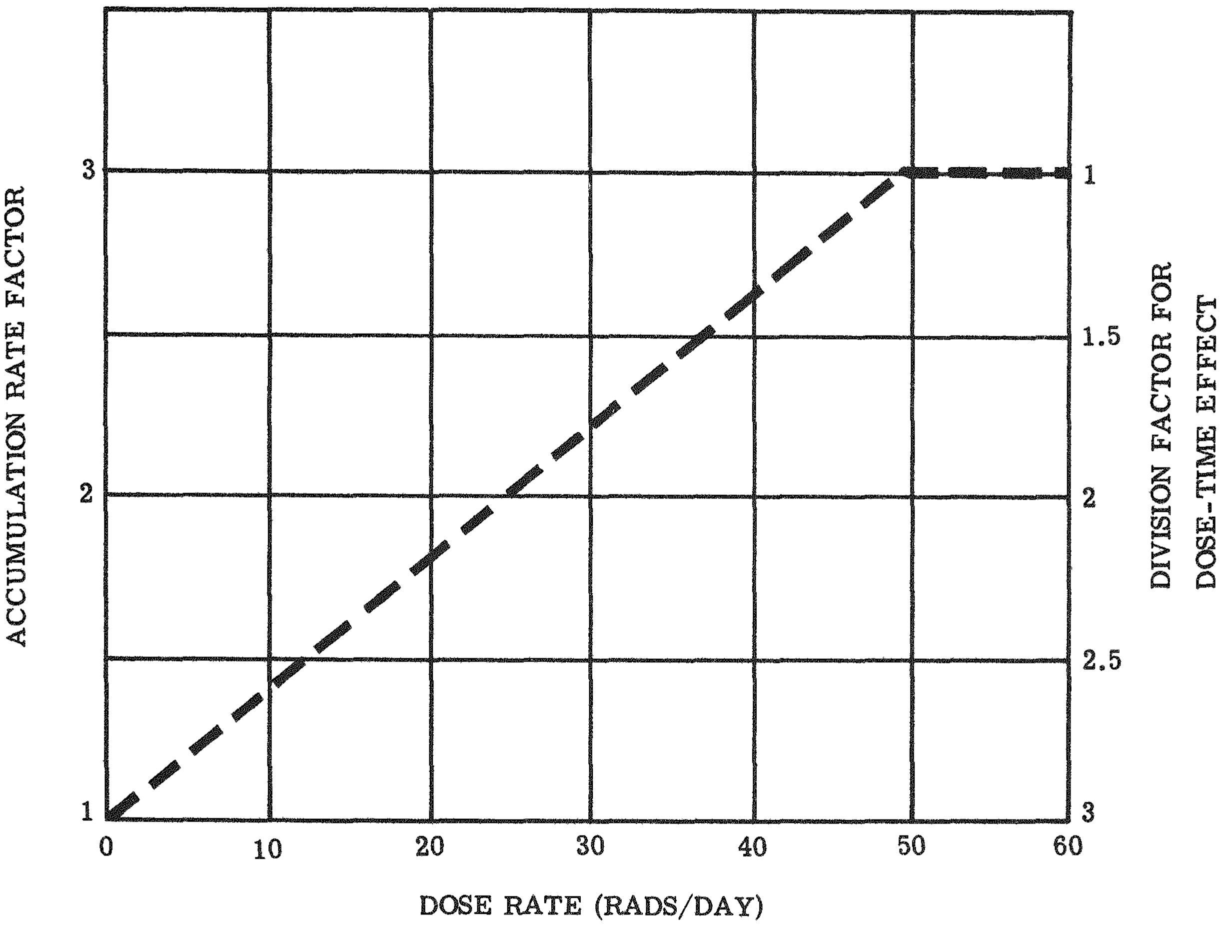

Figure 3

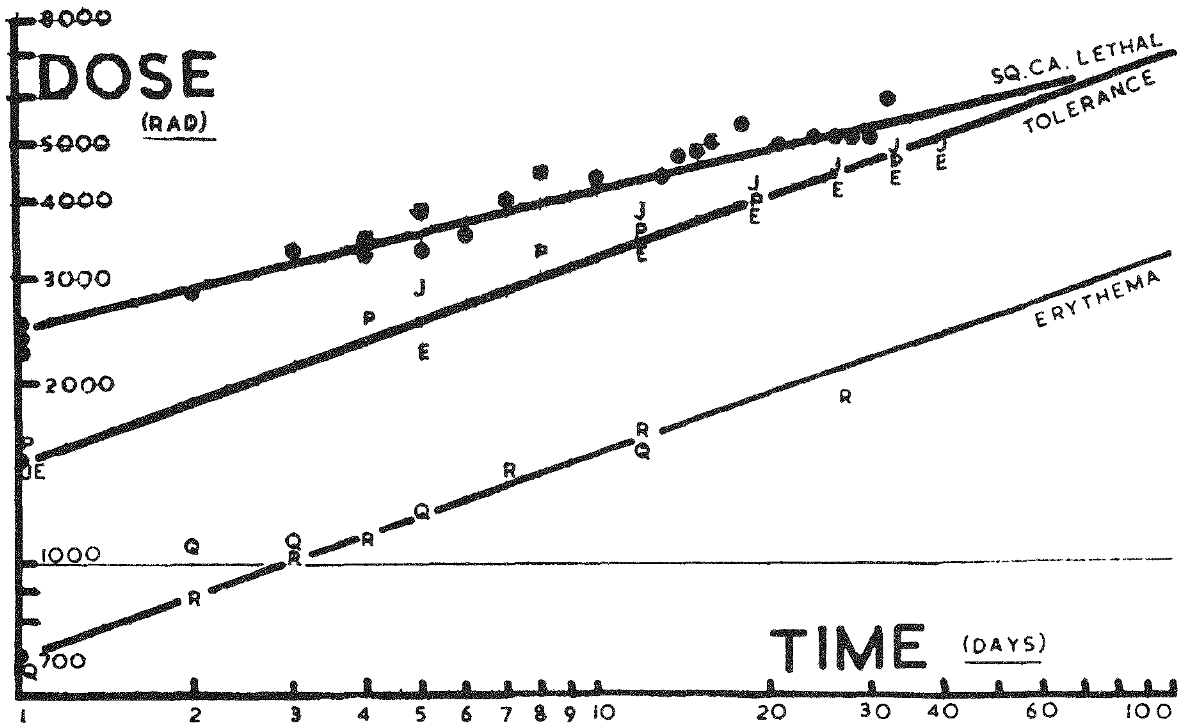

Figure 4

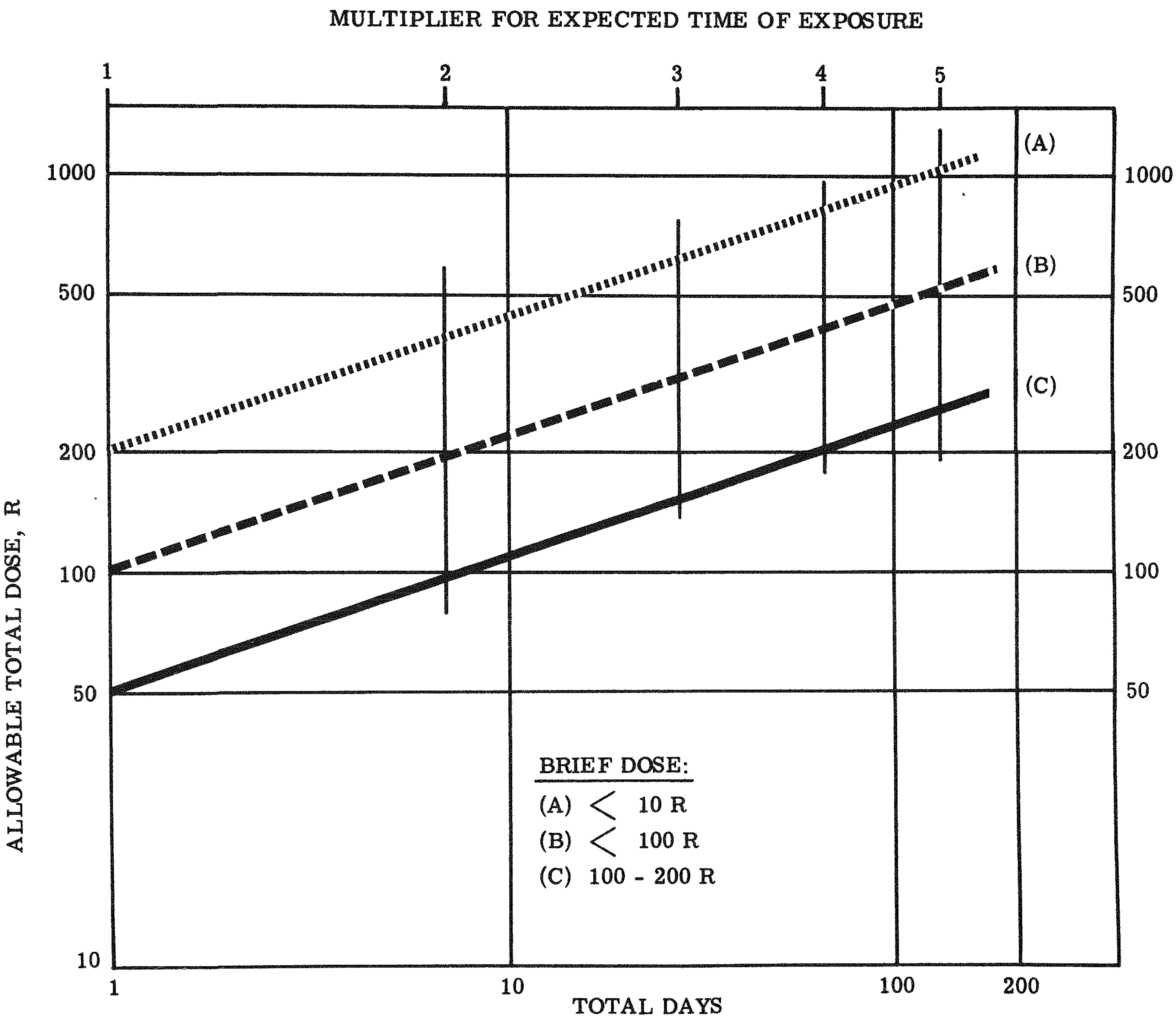
MULTIPLIER FOR EXPECTED TIME OF EXPOSURE
1
2
3
4
5
(A)
(B)
(C)
1000
500
200
100
50
10
ALLOWABLE TOTAL DOSE, R
BRIEF DOSE:
(A) < 10 R
(B) < 100 R
(C) 100 - 200 R
1
10
100
200
TOTAL DAYS

Figure 5

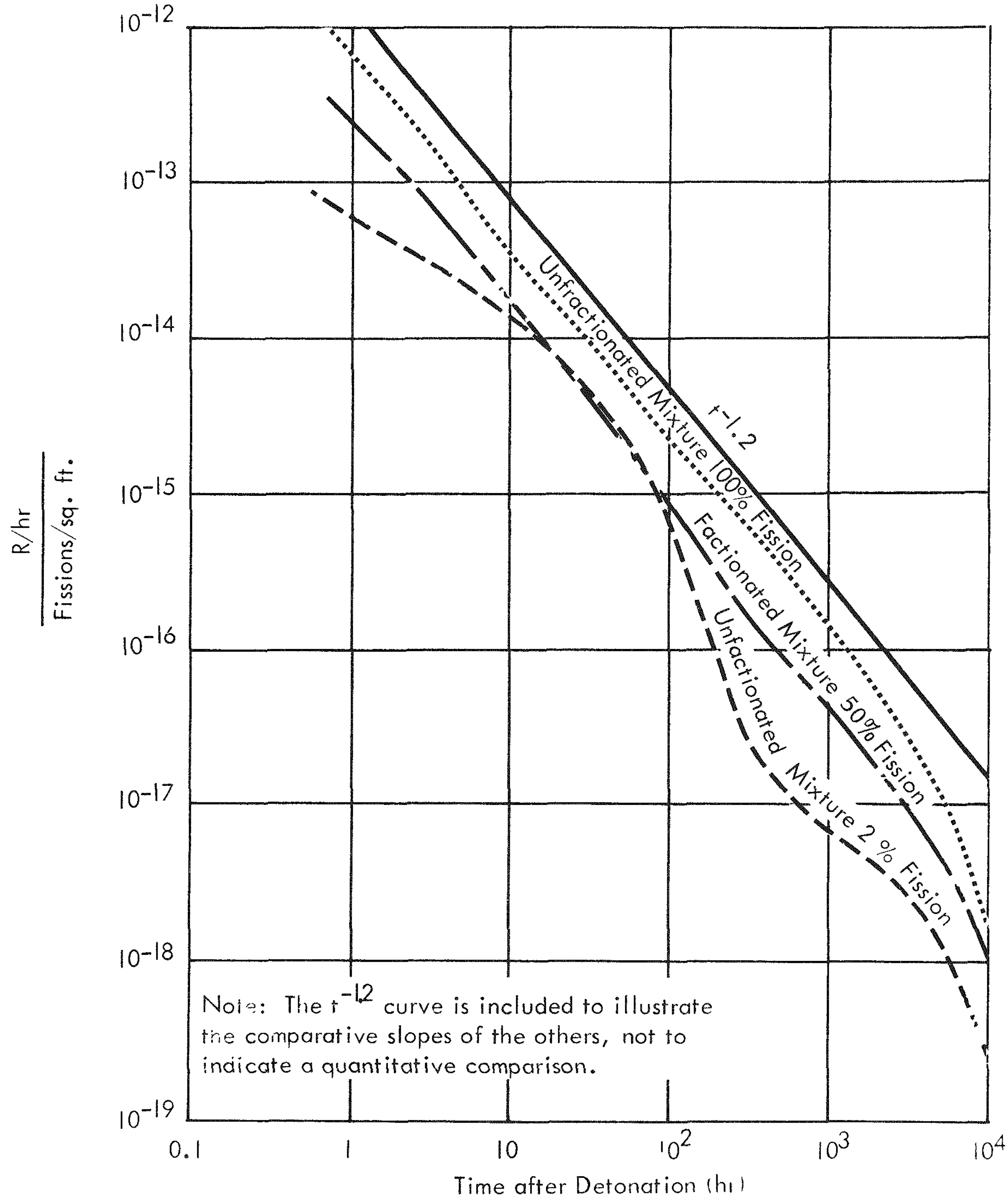

Figure 4 EXAMPLE CONVERSION FACTOR CURVES
(Contamination density to R hr)

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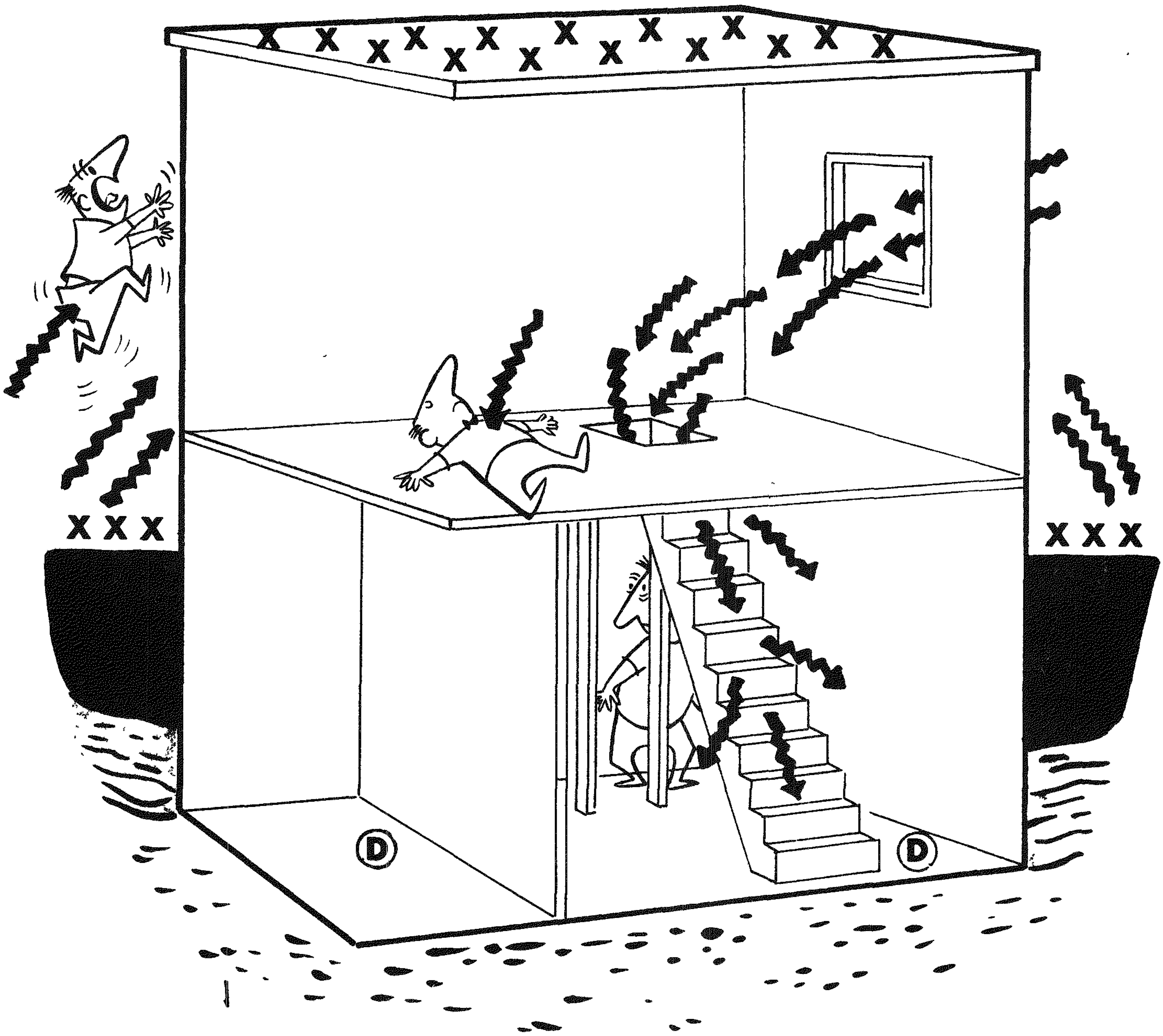
In summary, there is a continuing program of experimentation going on to check the accuracy of the present calculations used to predict protection from fallout. However, this program must be accompanied by another which studies the impact of inaccuracies on the various phases of the Civil Defense program. It is not unlikely that there is a range of protection factors for which much greater accuracy is required.



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7.4

The Vulnerability of Food to Nuclear Attack

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Summary

The U. S. grain stocks, which represent approximately 70% of the total U. S. stored food, have dropped rather steadily for seven years. In spite of this decrease, present total stocks seem ample to bridge a post-nuclear attack food gap until production rates reach consumption rates, although difficult emergency transportation problems must be solved. Livestock is particularly vulnerable to fallout radiation. A sample survey has indicated that only low protection factors (~ 2) are available in Tennessee for livestock. Nevertheless, based on the fallout pattern from a heavy attack against the U. S., it appears that even low protection factors may be extremely useful for livestock. Examples are given of inexpensive ways to provide P.F.'s of 3-5.

Introduction

Both the scientific literature and the popular press have recently emphasized the increasing seriousness of the world's food situation. It has been said that the world has consumed more food than it has produced for the last five years. In the United States, there has been worry expressed about the disappearance of the "surplus" grain supplies and many bills have been submitted to the present session of Congress to create by law strategic reserves of food, analogous to the strategic stockpiles of aluminum and other important materials presently maintained by the U. S. The world's alleged over consumption and the disappearing U. S. surpluses are directly related, as illustrated in Figure 1.

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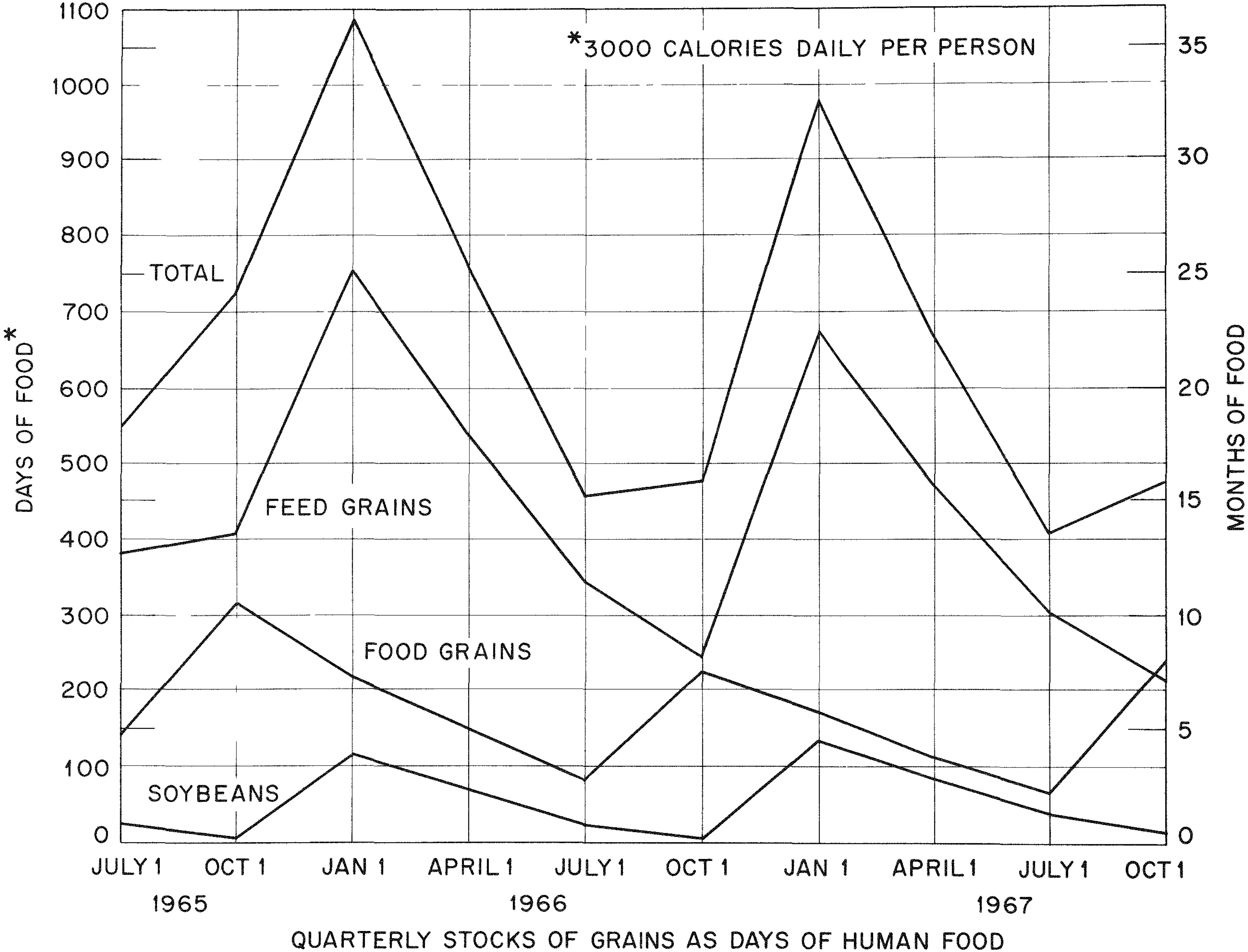

Figure 3

Figure 4

QUANTITY OF FOOD STOCKS BY STATES
July 1, 1967

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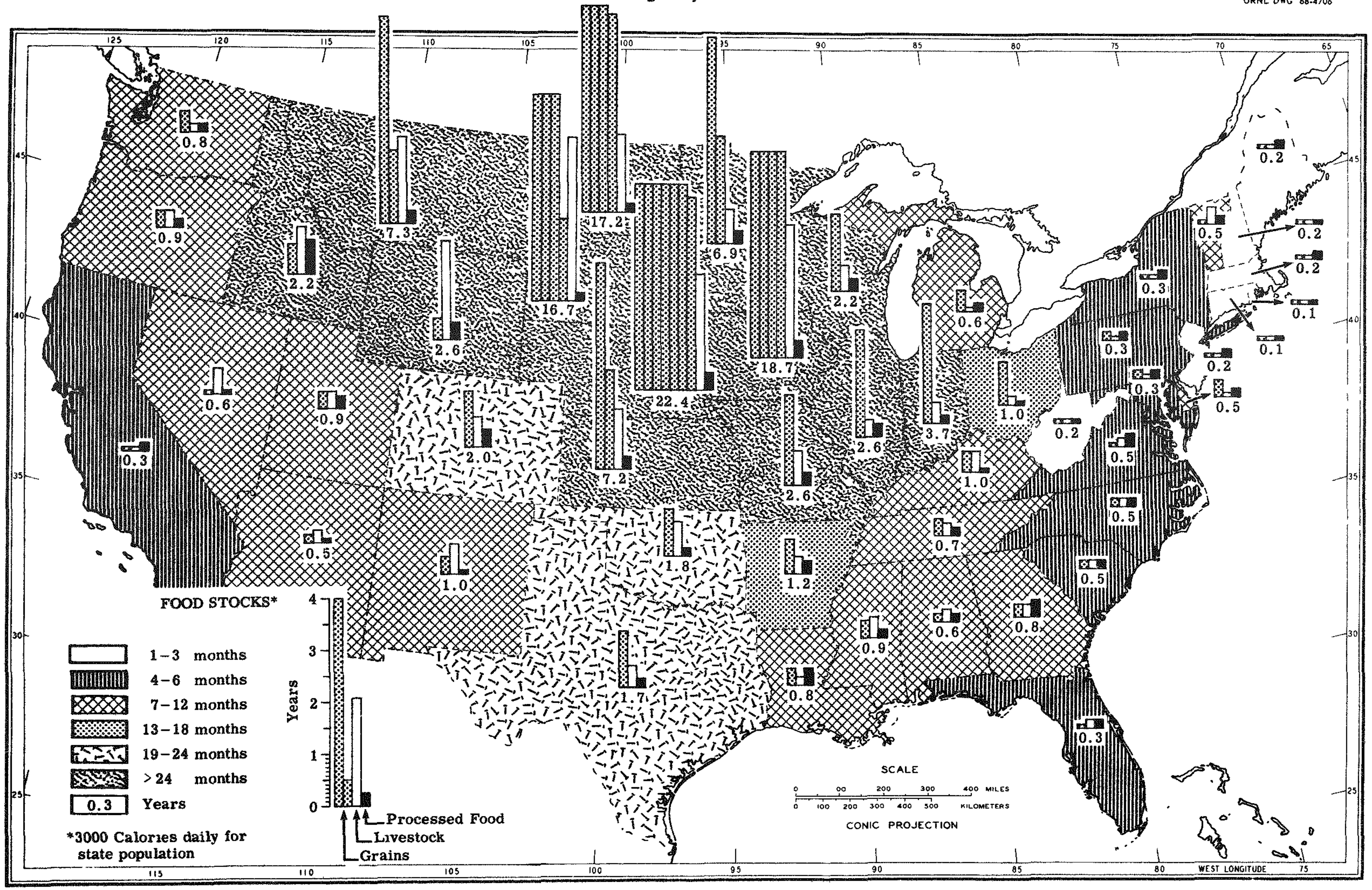
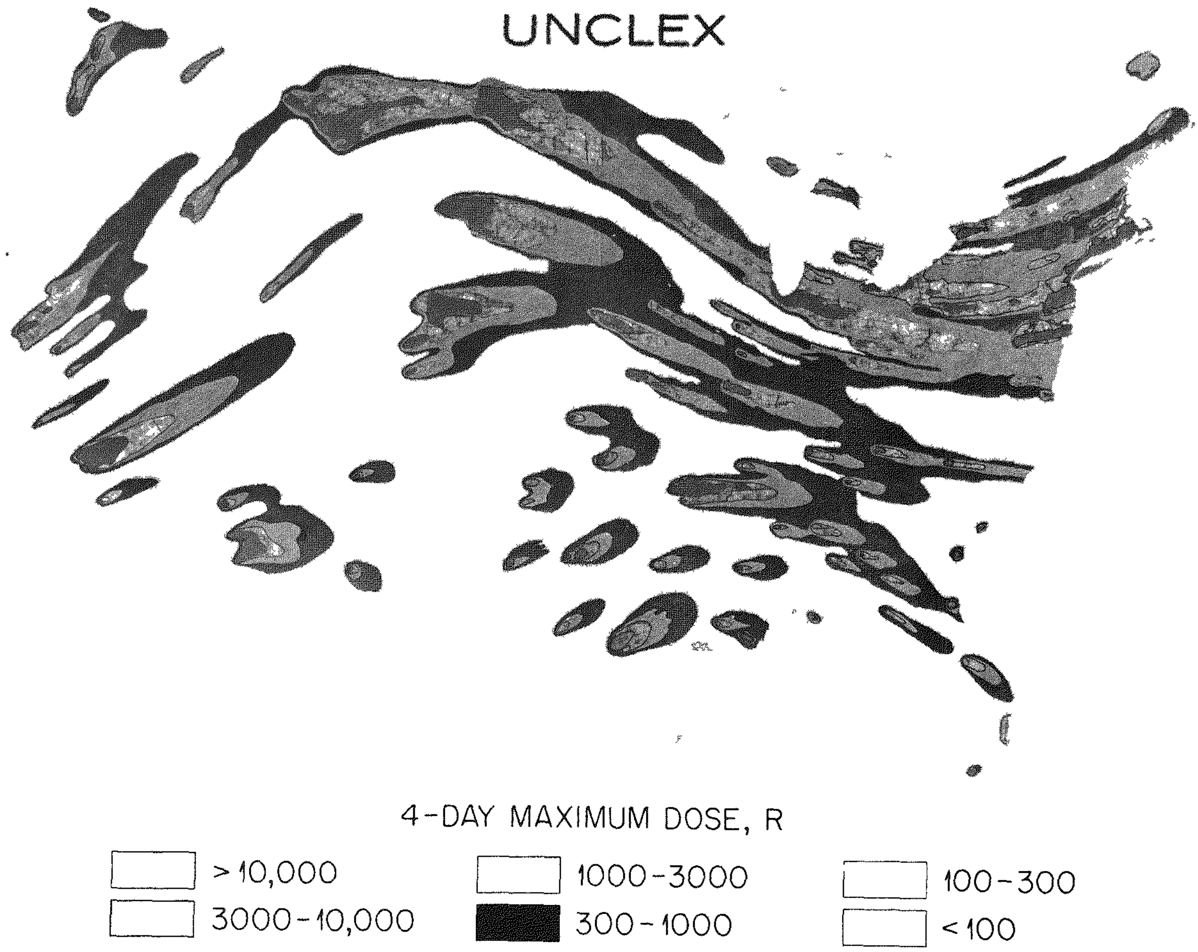


Figure 5. Nationwide UNCLEX



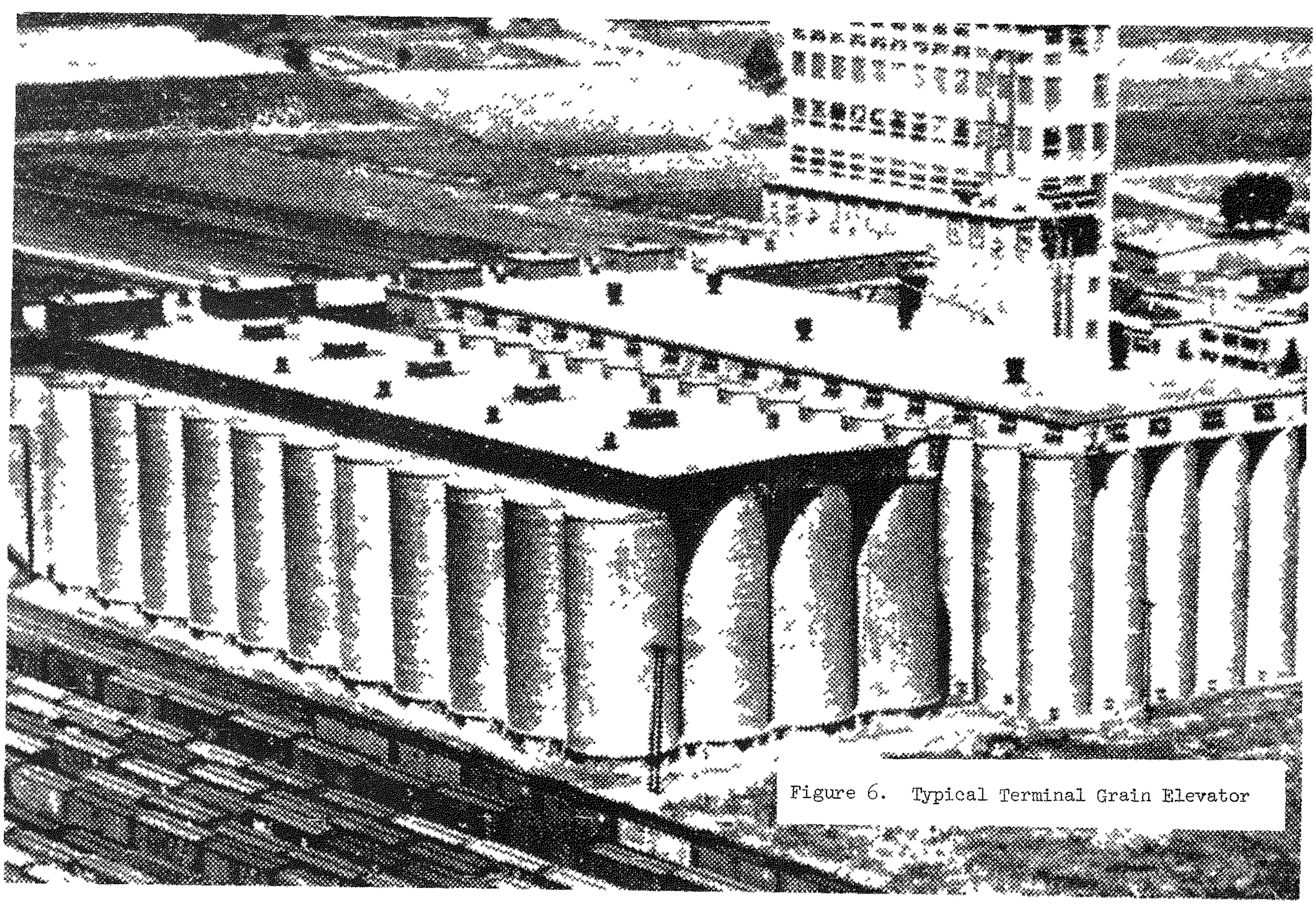


Figure 6. Typical Terminal Grain Elevator

cent of the U. S. grain would survive a heavy nuclear attack like UNCLEX. We conclude that food survival will be an unimportant problem compared with food transportation.

Vulnerability of Livestock

Livestock in stockyards in large cities might be exposed to the direct effects of nuclear weapons in an UNCLEX-like attack. However, in recent years there has been a trend toward the relocation of major meat packing plants in smaller U. S. cities. And the majority of the U. S. livestock is outside probable target areas at all times of the year. Therefore, the important danger to livestock is from fallout radiation.

We have studied U. S. livestock vulnerability by examining in detail the present levels of fallout protection available to livestock in Tennessee and the implication of these protection levels for survival after an UNCLEX attack.[7] We extended our results by a parametric study of low protection factors and concluded that P.F.'s between 2 and 5 may be very important for livestock survival. Included in this paper are two examples of inexpensive means of achieving such a level of protection.

The Tennessee data on livestock protection factors were collected in cooperation with the U. S. Department of Agriculture, during their regular livestock census in November and December, 1967. The same farms, selected on a statistical basis and used for the enumerative survey, were visited and the residents were questioned concerning the types of buildings available to protect their cattle and hogs. The location of the sample farms is shown in Figure 7.

The results of the survey are summarized in Table 1. Of the 205 farms visited, the results were analyzed for 111. The remaining 94 farms had either ten or less head of cattle or hogs or 10 or less acres, and the data from them was excluded as not being representative of the Tennessee livestock industry.

The average number of livestock buildings was 1.8 per farm and coincidentally their average protection factor was also 1.8. Nearly 87% of the cattle and 71% of the hogs could be sheltered, a somewhat higher percentage than was found by the Department of Agriculture survey of the dairy industry in 1962 in which 34% of the cattle in the southeast could be sheltered.[8]

The availability of water in the barns and the amount of feed on hand are also shown in Table 1. Although one-quarter of the barns had water, electricity was required for pumping and only one farm in the survey had an auxilliary motor-generator. The finding that an average of 100 day feed was available for the livestock was not unexpected since November-December is the beginning of the period for which stored feed is required for an average of 100 to 120 days.

The estimate by the farmers of the time it would take to put the livestock under cover is shown in Table 2. The length of time appeared to be more a function of the organization of the farms rather than the size, with the more specialized farms able to complete the movement in less time than the more general types.

The value of a protection factor of 1.8 for cattle under an UNCLEX attack was next estimated. The details of the UNCLEX fallout patterns in Tennessee are shown in Figure 8. Using a midlethal value of 550 roentgens for the maximum four-day dose values given in Figure 8, it was estimated

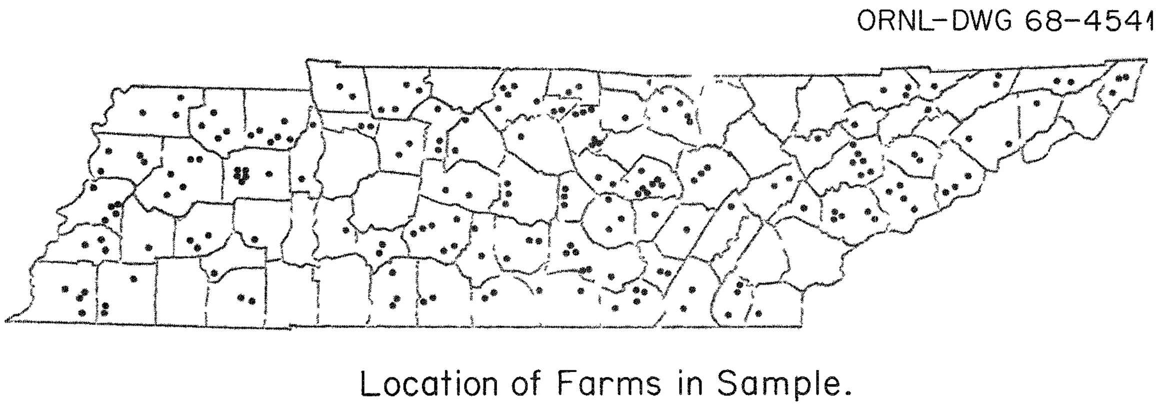


Figure 7

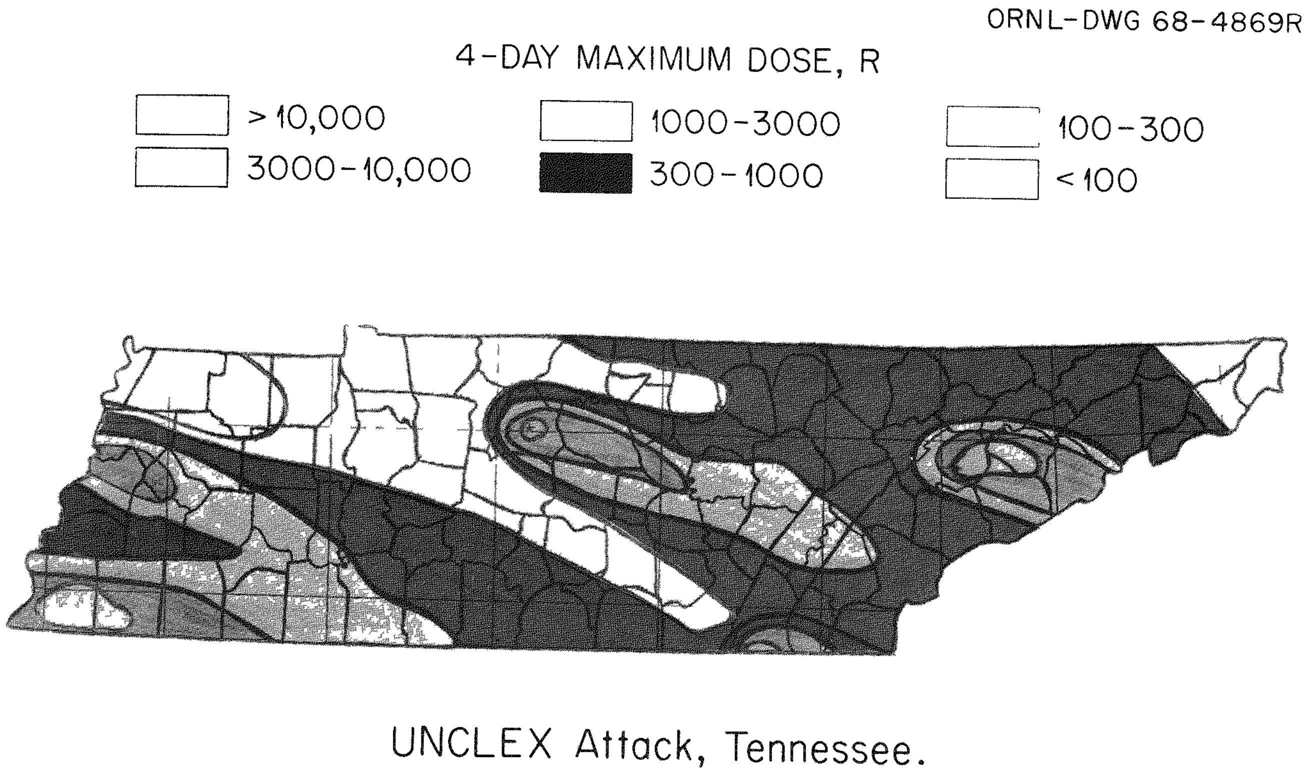


Figure 8

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Table 1

Protection—Food and Water Available on Farms

Livestock barns per farm	1.85
Average protection factor for barns	1.8
Livestock that could be sheltered:	
Cattle	86.7%
Hogs	70.8%
Barns with hay stored above livestock	52.0%
Barns with water	24.0%
Feed stored under cover on farm	98.9 days

ORNL DWG. 68-4628

Table 2

Estimated Time (by farmers) Required to Move Livestock to Shelter

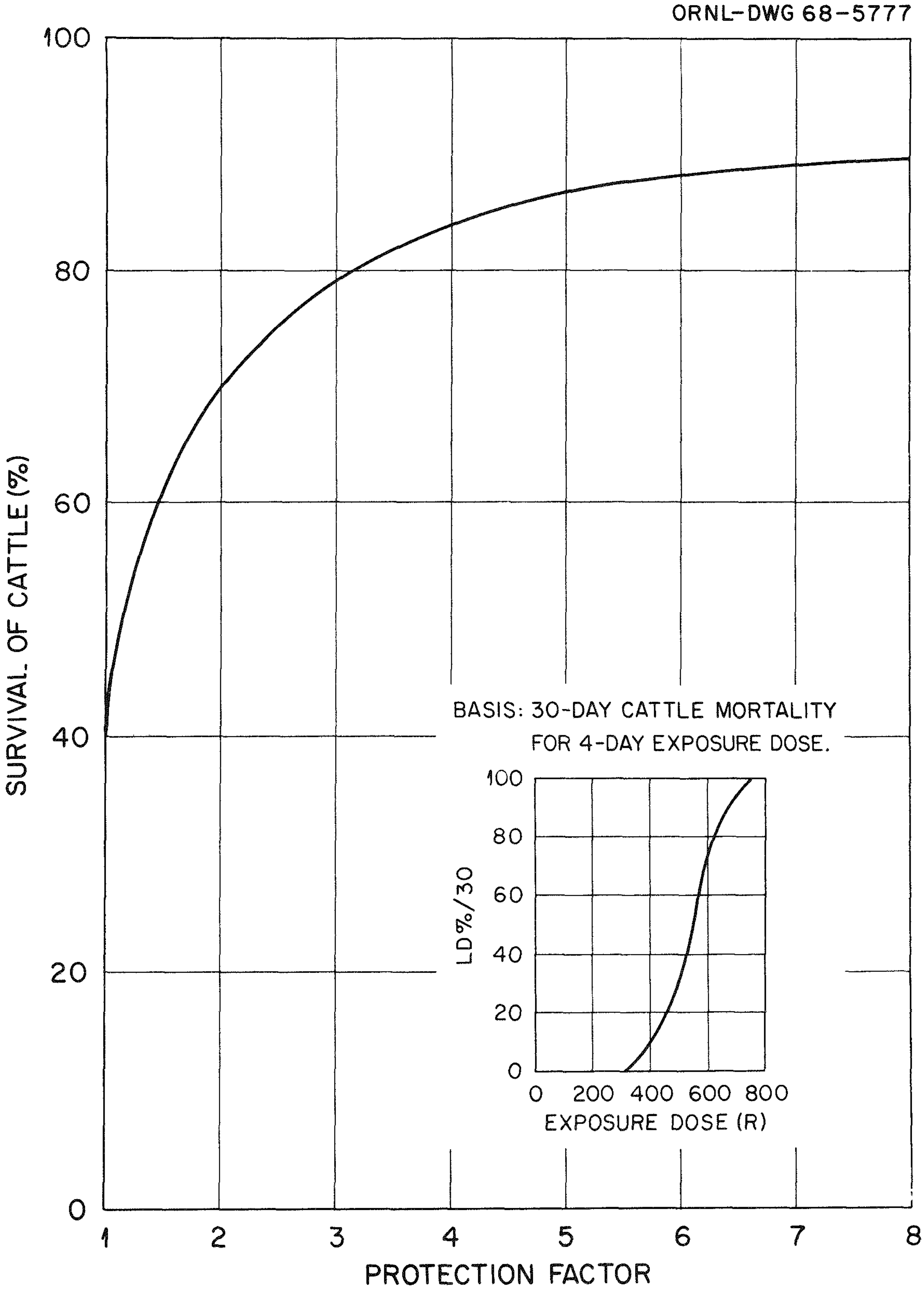
	1 hour	2 hours	3 hours	4 hours	> 4 hours
Percent of cattle in survey	30	53	73	78	87
Percent of hogs in survey	50	60	70	71	

that 33% of Tennessee cattle (the total cattle population on January 1, 1968 was 2.3 million) would die by the end of thirty days. If the protection factor were unity (no protection) 60% would die. Since hogs have a higher resistance to radiation than cattle, fewer would die in both cases.

The savings of 600,000 cattle with such a low P.F. encouraged us to examine the value of low protection factors in general. The results of the study are shown in Figure 9 together with the lethality curve used for the calculations. It can be seen that up to ninety per cent of the cattle in Tennessee could be saved by a protection factor near 10 (with little value from higher P.F.'s), but that 80% of all cattle that can be saved by fallout protection alone are saved by a protection factor of only 3.2.

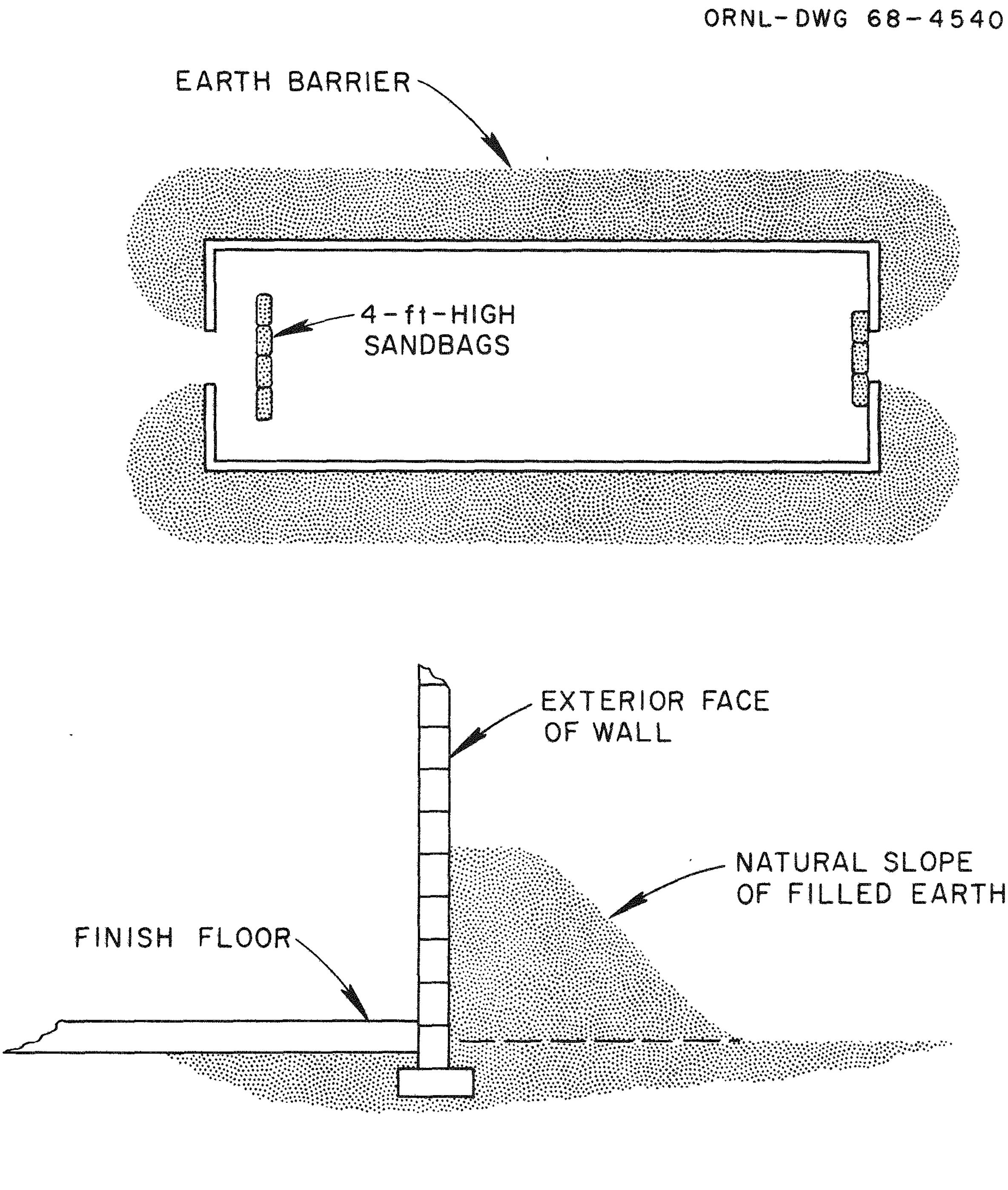
Such low values are rather easily obtained with any enclosed barns, even pole barns without hay lofts. Figures 10 and 11 show the use of mounded earth to provide, even with fully contaminated roofs and no lofts, P.F.'s of 3-4. These calculated values do not take into consideration self-shielding by the cattle in the barn, roughness of the contaminated ground, and rain decontamination of the roof.

We have concluded that low protection factors may be very useful in protecting livestock from nuclear attack. We hope to extend the P.F. survey nationally to test the legitimacy of treating Tennessee values as typical for the U. S. as a whole.



Effect of Protection Factors on Cattle Survival in Tennessee.
(UNCLEX Attack, 30 Days Post Attack)

Figure 9



Mounding Earth Around a Barn With Masonry Walls

Figure 10

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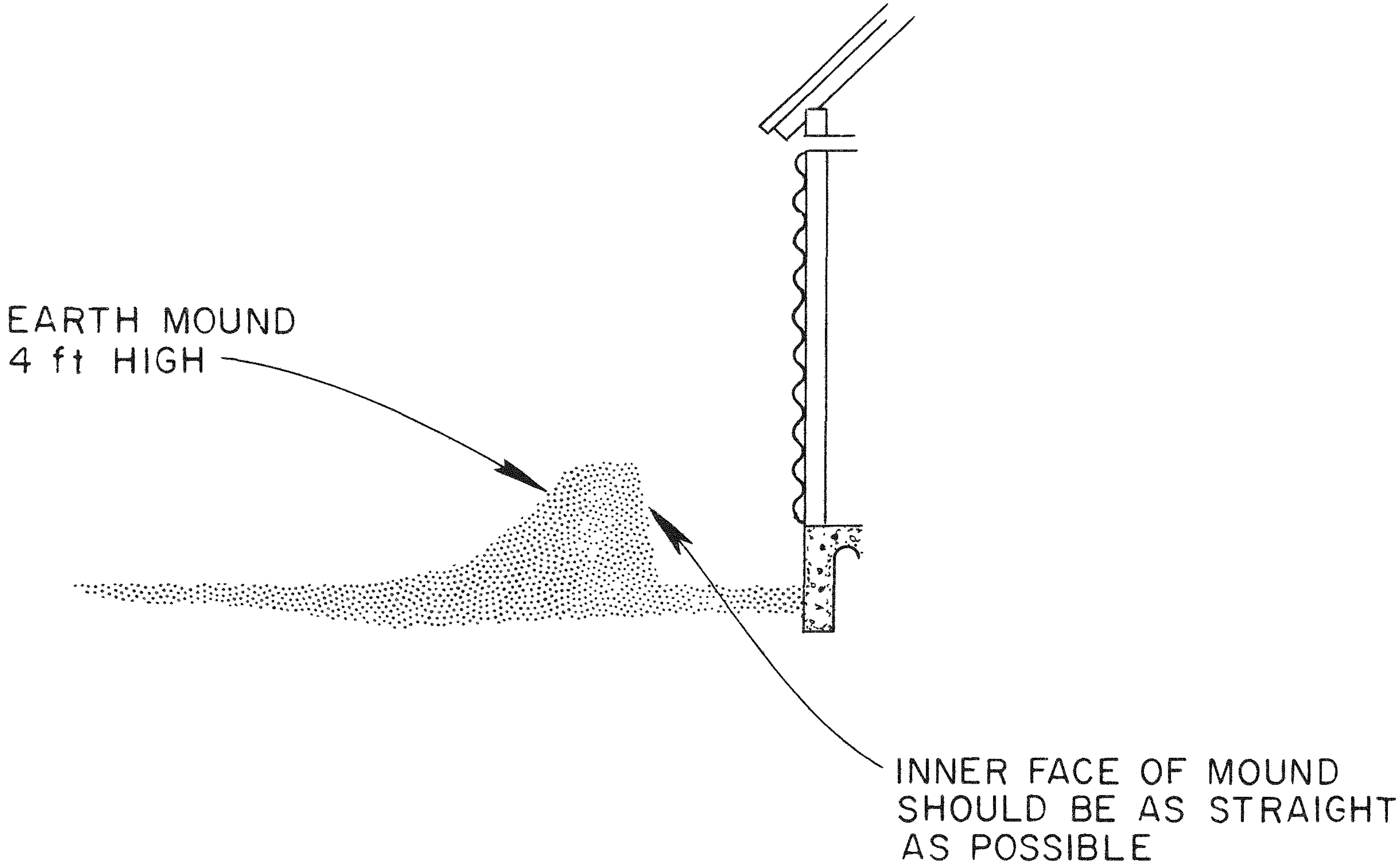

Mounding Earth Around a Barn With Frame or Pole Construction

Figure 11

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Session 1 | S U M M A R Y | Dr. C.F. Miller

Characteristics and Behavior of Local Fallout

The report of working group 1 summarizes the current state of knowledge on several of the characteristics and behavior of local fallout pertaining to the technical aspects of radiological protection of the public in a nuclear mass disaster and certain operational questions pertaining to this overall problem. It is assumed that the information provided is to serve as a basis for indicating the nature and degree of radiological hazards that may be considered by other working groups. The discussion emphasizes an envisioned disaster that may result from a relatively large nuclear explosion near ground surface whereby the fallout would affect a large segment of the public rather than that from a small nuclear reactor accident whose radiological effects would cover only a small, and perhaps isolated rural area.

In view of the time constraint on the deliberation, consideration was limited to a few general conclusions regarding the state of knowledge and information on the following general topics: the fallout properties and characteristics with respect to particle sizes, particle composition, solubility, radioactive decay, and radioactive concentration; the distribution of fallout over the landscape and the magnitude of the radiological hazards; the deposition process on local areas and factors affecting the beta and gamma radiation levels; the redistribution of the fallout particles by natural causes; the use and availability of fallout model for operational studies and exercises. Our summary is as follows:

1. The major sources of radiological hazard to the public and to plants and animals in a fallout area are due to gamma and beta radiation; alpha rays from fallout from nuclear explosions need not be considered.

2. Fallout hazards near the point of a nuclear explosion are secondary to those from the immediate effects (blast and fire). Beyond the range of these effects in a downwind direction, the predominating fallout hazard to humans is from the external gamma radiation. However, the relative importance of the hazard from internal contamination increases with distance from the point of the explosion but the absolute level of the hazard from this source, with possible exception of the I-131 in infants thyroids, would rarely exceed that from the external gammas if proper precautions are taken. It should be noted that these potential hazards can be reduced a great deal by protective shelters and other civil defense measures. With a good shelter system, the relative order of the two types of hazards at the higher fallout deposit locations could be reversed.

3. No precise definition of local fallout is possible to cover all situations. On a conservative basis and with respect to gamma radiation levels requiring use of shelters, it may be defined for explosions in the kiloton to megaton yield range where the fallout arrives within the first day after the explosion and where the smallest particle that arrives has a diameter of more than 20 microns, the average being much higher. And since the human lung retains particles with diameters of about 1 to 5 microns through inhalation, no serious inhalation hazard is expected to occur in the local fallout area even for people that do not take shelter and do not use filtration devices.

4. The arrival of local fallout particles larger than about 30 to 60 microns may be detected by feel on the nose, forehead, and lips of exposed persons. The local fallout particle rain-out may be seen by impaction on white objects and, after a short time of deposition, as a layer of dark sand or soil particles on roads, cars and other exposed objects. As a rough rule of thumb, a nuclear detonation on the surface throws up about one megaton of soil per megaton of explosive yield.

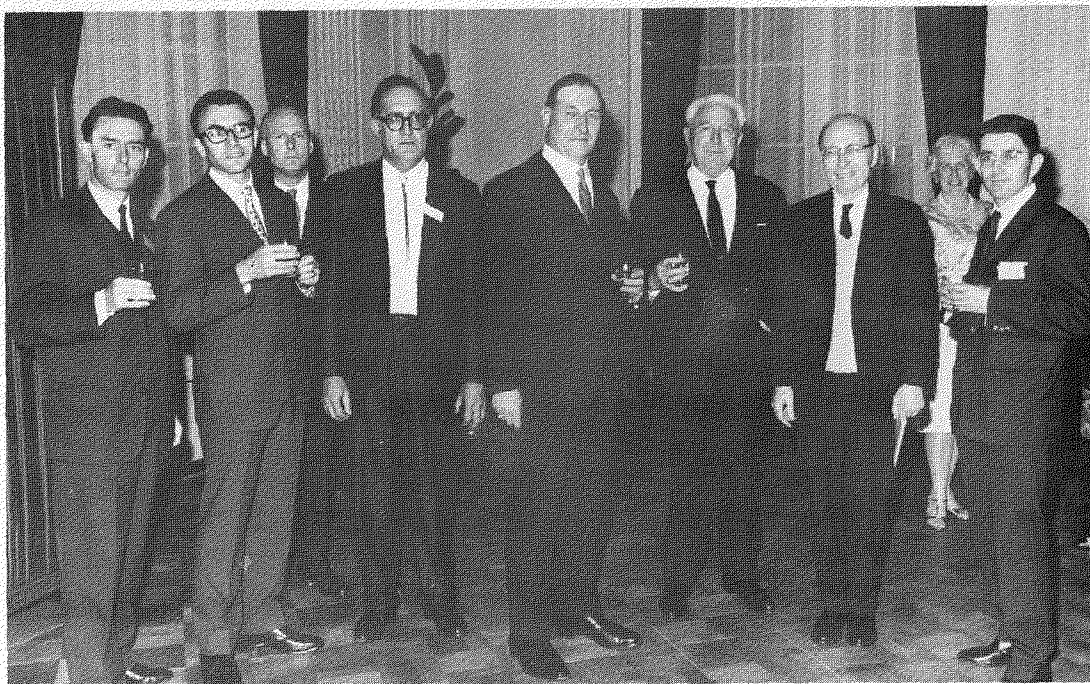
5. Knowledge about the behavior of sand and dust particles can be used to infer behavior of fallout particles after deposition on paved areas and roofs with respect to their subsequent movement by wind and rain.

6. No fallout model exists that will reliably predict all radiological hazards at a given geographical location, not to mention the combined exposure doses from beta and gamma radiation on plants, animals, insects and humans. Many local factors are not considered in these mathematical representations. The major usefulness of these models is to investigate the general nature of the problem and to assist in designing protective measures and exercises. If meteorological data are available, the general region of fallout can be predicted even though accurate estimates for a given location are not possible.

7. The solubility of radionuclides in fallout generally increases as the particle size decreases (i.e., the solubility increases with downwind distance from ground zero). Not all radionuclides are soluble in water or in stomach acids. Major nuclides found to be soluble are I-131, Sr-89, Sr-90 and Cs-137.

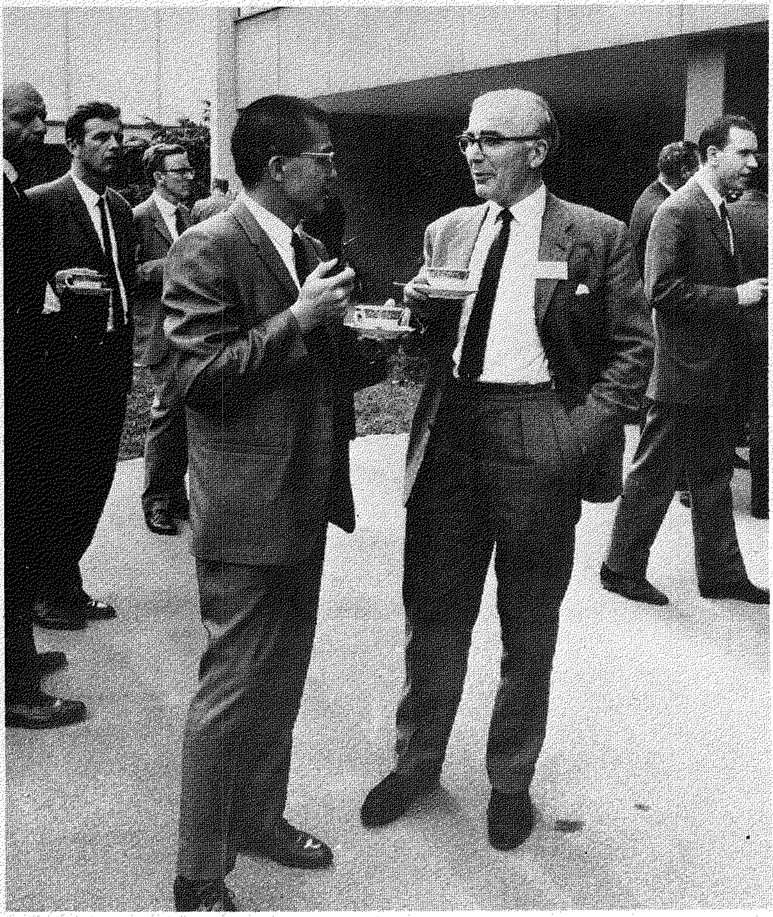
8. Fallout contains fission products, induced activity from the weapon materials and induced activity from soils. In some cases, Np-239 is an important contributor and its ionization rate may be equal to that of the fission products at about 4 days after detonation (it decays away rapidly thereafter). The fission products tend to be fractionated according to particle type; however in the local fallout, the fractionation effect does not result in large differences in the gross exposure rate decay of the radioactivity.

9. No papers that described the nature and behavior of possible fallout from accidents in nuclear installations were presented. However, it was mentioned that the characteristics, behavior, area covered, and form of radiation hazard from this source of fallout would not be expected to be similar to that from nuclear explosions. The major radionuclide present in the fallout from the accidental destruction of nuclear weapons is plutonium; but the behavior of fallout particles and associated hazards again are dissimilar to those from nuclear weapon fallout. In other words, the properties of and hazards from the fallout from these two sources cannot be described on the basis that they would be like those from small nuclear explosion fallout events.



Front row: O. Burkhardt, Administrative Secr. of the Symposium - S. Prêtre, Pres. of "Fachverband für Strahlenschutz" - Dr. C.F. Miller, URS Corp., Burlingame, California - Bundesrat L. von Moos, Member of the Swiss Government, Minister of Justice and Police - W. König, Dir. of the Swiss Federal Office of Civil Defense - Prof. E.P. Wigner, Princeton Univ., Nobel Prize in Physics 1963 - H. Brunner, Scientific Secr. of the Symposium.

LeRoy-Courvoisier-Rust-Hasterlik, perhaps conceiving the next edition of NCRP report 29.



Leong-Scott Russel trying coffee as an easily available radioprotective drug!

On the far left: Mr. Kaufmann

Sharp Cook - Brunner - Maushart and the folkloric cow bell which served as an effective sword of Damocles for every speaker tempting to be too long-winded!